The Globalization of Knowledge in History

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Based on the 97th Dahlem Workshop

Edited by Jürgen Renn

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In memory of Peter Damerow and Malcolm D. Hyman

Contents

Preface

Jürgen Renn

This volume presents results of an interdisciplinary research project on the globalization of knowledge. The project is centered at the Max Planck Institute for the History of Science. It was launched in 2007 at the 97^{th} Dahlem Workshop on *Globalization of Knowledge and its Consequences*, a Dahlem Conference hosted by the Free University Berlin and supported by the Deutsche Forschungsgemeinschaft (DFG). The Dahlem Conferences, with their unique mode of scholarly interaction, have played a key role in fostering an interdisciplinary cooperation that covers a vast array of disciplines, cultures and historical periods. I am grateful to Katharina Ochse, as well as to my colleagues from the Advisory Board of the Dahlem Conferences, for initiating us into the procedures of this workshop model. The numerous documents, papers, commentaries, reviews and discussion statements that have been produced in the process have all turned out to be essential in producing this volume.

The project is part of the research program of a historical epistemology whose aim is to contribute also to the reflexivity of present science and its institutions. It pursues a comparative history of knowledge in which present processes of globalization are conceived as the outcome of historical developments and their interactions. The four research foci of the project have been chosen such that theoretical claims can be validated with reference to outstanding historical phases in which knowledge production, transmission and transformation were critical for advancing processes of intercultural exchange. The theoretical framework developed in the course of the project comprises a core set of concepts which should be extended and revised in the course of further research.

The scholarly network, established in 2007, has since been significantly expanded. The participating scholars have collaborated in a variety of meetings and exchanges dedicated to the production of this working group volume. In addition to the papers originally submitted at the Dahlem Conference, a number of invited contributions have been integrated. All contributions have been peer-reviewed and also partly revised by members of an internal board, which met on several occasions to discuss the overall results of the cooperation and their presentation in the introductory survey chapters to each of the four parts of this volume. The internal board comprised Peter Damerow, Kostas Gavroglu, Malcolm D. Hyman, Dagmar Schäfer, Matthias Schemmel and Milena Wazeck. Furthermore, Jens Braarvig, Eva Cancik-Kirschbaum, Yehuda Elkana, Fynn Ole Engler, J. Cale Johnson, Dan Potts, Milena Wazeck and Helge Wendt made quite substantial contributions or even drafted texts that are now integrated into the survey chapters. These chapters introduce each of the four parts of this volume which correspond to the research foci of the project.

We are grateful to all those who participated in the Dahlem Conference, and in particular, to the moderators and the rapporteurs for their lively discussions and manifold contributions to this volume. In the long process of revising and supplementing the original papers, the emerging volume was read and commented upon by several colleagues who made contributions that were also incorporated mostly into the survey chapters. We are grateful to Amund Bjørsnøs, Hansjörg Dilger, Gideon Freudenthal, Günther Görtz, Albert Presas a Puig, Martin Thiering, Gerd G. Wagner and Dirk Wintergrün for providing such contributions. In the attempt to connect the themes touched upon in this volume with the vast secondary literature available on them, we received and are grateful for the suggestions of Henry Junowicz, Horst Kant, Dietmar Kurapkat, Stephen Levinson, Veronika Lipphardt, Irad Malkin, Peter McLaughlin, Stefan Trzeciok and Han Vermeulen. For their help in the editorial process, we would also like to thank Heidi Allene Henrickson, Oona Leganovic, Barbara Lenk, Susan Richter, Rafaela Teixeira Zorzanelli and especially Marius Schneider. We would also like to acknowledge the close cooperation with the Excellence Cluster TOPOI – The Formation and Transformation of Space and Knowledge in Ancient Civilizations.

The preparation of the introductory survey chapters was originally in the hands of the editor and Malcolm D. Hyman. Unfortunately, Malcolm died suddenly in September 2009, just after the first survey had been completed. Malcolm, a historian of science, linguist, classical philologist, Sanskrit scholar and information scientist, was one of the driving forces behind this research project. On his own initiative, he extended the project to launch a history of multilingualism which is now being pursued at the Max Planck Institute for the History of Science. Malcolm's ideas are omnipresent in this volume. He was an outstanding scholar and a warm and gentle human being, a unique mind whose loss is irreplaceable.

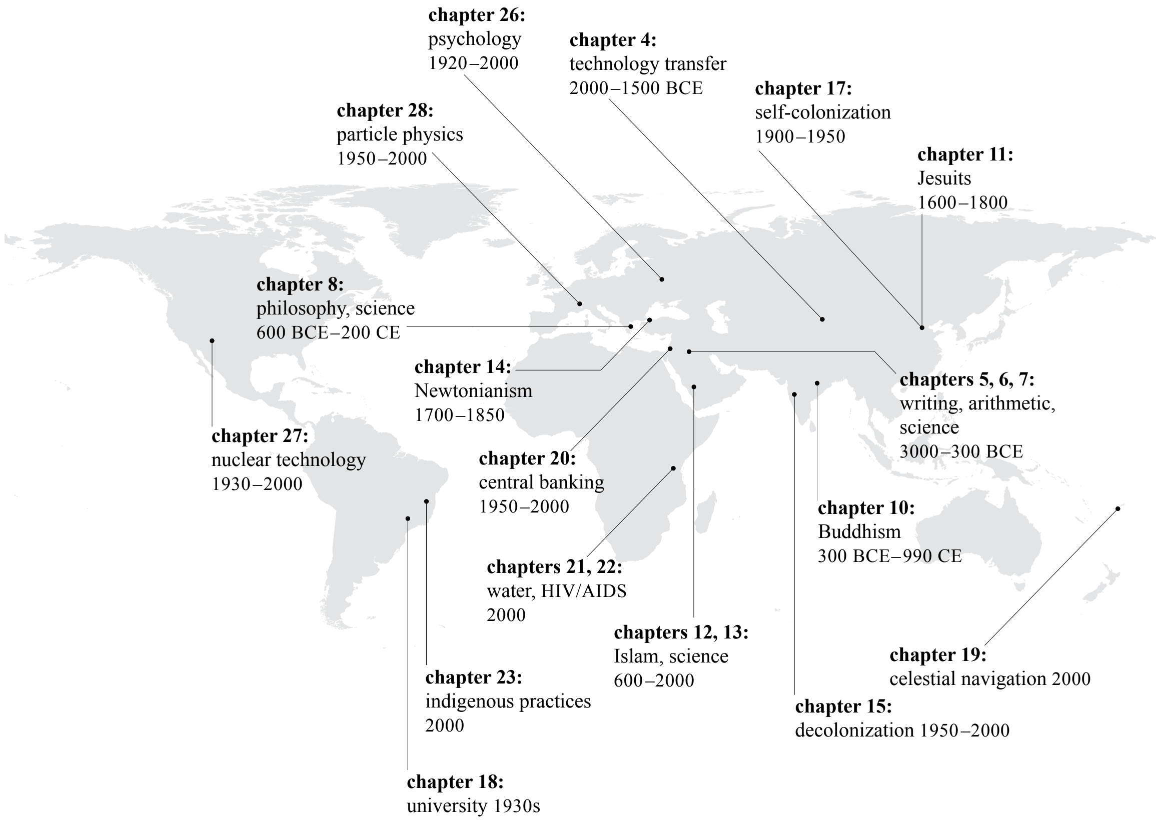
Up until he sadly passed away in November 2011, the mathematician and historian of science, Peter Damerow, the other driving force behind this project, worked intensively on this book. Without his initiative and persistence, it would not have come into being. He did not consider the history of science to be a specialized discipline, but rather a research area that was part of his comprehensive interest in the development of human cognition. In this sense, he was a pioneer of an interdisciplinary conception of the history of science and of its extension toward a history of knowledge, as is reflected in the subject matter of this book. His early works on the emergence of writing and counting make clear that the emergence of abstract concepts can be understood only if we take seriously the role of those representations of knowledge that are given in concrete historical cases, and the potential for actions and reflection they enable, as for instance, the specific role played by cuneiform script tablets in the administration of Babylonia. This insight enabled him to contribute to completely different fields, for instance, to cultural anthropology and more generally to the study of non-European knowledge traditions. This book hopefully somewhat reflects the vision of a developmental history of knowledge that Peter Damerow brought to the Max Planck Institute when he joined it in 1994.

Apart from the contributions of Malcolm D. Hyman and Peter Damerow, it was above all the editorial work of Lindy Divarci that made this work possible. She was at the center of the network of communications with authors and referees, implementing revisions, compiling the bibliography, adjusting formats, and ensuring the coherence of the enterprise. The material forming the basis of this volume was quite heterogeneous, originating in different disciplines each with their own standards and from different linguistic backgrounds, with greater or lesser affinity to academic English. Lindy's competence and professionality in transforming disparate contributions into chapters of a book are unsurpassed.

The volume should serve as an encouragement to all those who risk taking on intellectual challenges that cannot be confined to disciplinary fields. It is not meant to be a documentation of definitive results, let alone a comprehensive historical survey, but rather presents research in flux. This book is an invitation to other scholars to contribute to the ongoing work and discussions on the globalization of knowledge in history.

Jürgen Renn, Berlin, 12 April 2012

World Map – Chapter Overview



chapter 1: globalization in history
chapter 2: literature survey
chapter 3: origins of science
chapter 9: empires and religions
chapter 16: local knowledge
chapter 24: modern science
chapter 25: future university
chapter 29: molecular biology
chapter 30: chemistry and energy
chapter 31: climate
chapter 32: Epistemic Web

About the Contributions

Chapter 1. Globalization of Knowledge in History: An Introduction sketches a general epistemological framework for studies of the globalization of knowledge in history.

Chapter 2. Knowledge and Science in Current Discussions of Globalization reviews the role that knowledge and science play in recent literature on globalization processes and their history.

PART 1

Chapter 3. Survey: From Technology Transfer to the Origins of Science develops the general epistemological framework, focusing on the transfer of technology in the ancient world and on the role of globalization processes for the origins of science.

Chapter 4. Technological Transfer and Innovation in Ancient Eurasia discusses interpretative models of and concrete archaeological evidence for technology transfer in ancient Eurasia and, in particular, Western influences in the development of Chinese metallurgy.

Chapter 5. Writing, Language and Textuality: Conditions on the Transmission of Knowledge in the Ancient Near East analyzes notational systems in the Ancient Near East as *Kulturtechnik*, developing a general perspective on the representation of knowledge by writing systems.

Chapter 6. The Origins of Writing and Arithmetic reviews the common origins of writing and arithmetic in the administrative techniques of the Ancient Near East.

Chapter 7. Globalization of Ancient Knowledge: From Babylonian Observations to Scientific Regularities deals with the structure of scientific knowledge in Mesopotamian culture, focusing on the astronomical diaries as the foundation of Babylonian astronomy.

Chapter 8. The Creation of Second-Order Knowledge in Ancient Greek Science as a Process in the Globalization of Knowledge argues that the creation of Greek science involved the formation of second-order knowledge based on stimulus diffusion related to the spread of practical knowledge from cultures such as Egypt and Babylonia.

PART 2

Chapter 9. Survey: Knowledge as a Fellow Traveler develops the general epistemological framework, focusing on how knowledge was transmitted as a fellow traveler during the spread of empires and religious systems.

Chapter 10. The Spread of Buddhism as Globalization of Knowledge discusses how knowledge spread with Buddhism in Eurasia, focusing in particular on the importance of literacy.

Chapter 11. The Transmission of Scientific Knowledge from Europe to China in the Early Modern Period discusses the transmission of European scientific knowledge by Jesuit missionaries to late Ming, early Qing China, interpreting this process as a partial integration of two systems of knowledge.

Chapter 12. Normative Islam and Global Scientific Knowledge discusses the way in which normative Islam acted as a comprehensive worldview, shaping the development of different types of knowledge.

Chapter 13. From Khwarazm to Cordoba. The Propagation of Non-Religious Knowledge in the Islamic Empire discusses the transfer and transformation of Greek knowledge via the multi-faceted culture of the Islamic Middle Ages from antiquity to the Western Middle Ages.

Chapter 14. The Sciences in Europe: Transmitting Centers and the Appropriating Peripheries focuses on the introduction of Newtonian ideas into the Greek intellectual space of the Ottoman Empire in the eighteenth century.

Chapter 15. The Naturalization of Modern Science in South Asia: A Historical Overview of the Processes of Domestication and Globalization discusses the globalization of science in the context of the European colonial expansion to India and on the encounter between modern science and South Asian knowledge systems.

PART 3

Chapter 16. Survey: The Place of Local Knowledge in the Global Community deals with the role of local knowledge in a globalizing world, extending the general epistemological framework to develop notions such as second-order local knowledge.

Chapter 17. Taking China to the World, Taking the World to China: Chen Hengzhe and an Early Globalizing Project represents a case study dealing with the cultural project of a Chinese intellectual, Chen Hengze, who at the beginning of the twentieth century became China's first female professor of Western history.

Chapter 18. The Introduction of the European University System in Brazil discusses the foundation of the first university in Brazil in the 1930s with a particular focus on the controversial role of mathematics teaching between practical and theoretical traditions.

Chapter 19. Celestial Navigation and Technological Change on Moce Island discusses the complex interaction between globalized technologies and local knowledge of navigation in the Pacific.

Chapter 20. Translation of Central Banking to Developing Countries in the Post-World War II Period: The Case of the Bank of Israel discusses the transmission of central banking to peripheral countries after the Second World War and the ways in which a globalized model was adapted to local circumstances.

Chapter 21. On Juridico-Political Foundations of Meta-Codes is based on an ethnographic case study of the organizational and technical improvement of waterworks in three cities in Tanzania, discussing knowledge practices of encounters and negotiations between international experts and local actors.

Chapter 22. The (Ir)Relevance of Local Knowledge: Circuits of Medicine and Biopower in the Neoliberal Era is based on field work in rural and urban Tanzania, exploring different aspects of the interconnection between HIV/Aids and social relationships in the context of globalization and modernity.

Chapter 23. The Transformations of Knowledge Through Cultural Interactions in Brazil: the Case of the Tupinikim and the Guarani discusses school education in two ethnic communities in the state of Espírito Santo in Brazil, exploring how abstract concepts such as symmetry can be related to local practices.

PART 4

Chapter 24. Survey: The Globalization of Modern Science reviews the development of scientific knowledge and its globalization from the early modern period to the present. It introduces in detail the notions of socio-epistemic complex and socio-epistemic evolution, elaborating the general theoretical framework.

Chapter 25. The University of the 21st Century: An Aspect of Globalization develops a vision for the university of the twenty-first century, suggesting an epistemological rethinking characterized as a transition from local universalism to global contextualism.

Chapter 26. The Soviet Psychologists and the Path to International Psychology discusses the development of a new kind of psychology in the 1920s and 1930s by a group of Soviet researchers, characterized by taking into account the cultural and material conditions in which people live. It claims that their ideas formed the basis for a genuinely international psychology.

Chapter 27. The Global Diffusion of Nuclear Technology reviews the emergence and globalization of nuclear science and technology since World War II. It discusses in particular the ensuing new role of scientists in international politics, the emergence of the industrial military complex, the establishment of the non-proliferation regime and the current challenges of the spread of nuclear technology with intrinsically dual-use character.

Chapter 28. The Role of Open and Global Communication in Particle Physics discusses the role of knowledge sharing and open communication in high-energy physics. The community of particle physicists has played a pioneering role in establishing open-access publishing and open-data sharing as future models for scientific communication.

Chapter 29. Internationalism and the History of Molecular Biology traces the changes in character of an unparalleled international cooperation, from the state of self-organization to an increasing involvement of agencies and governments as well as the emergence of economic opportunities.

Chapter 30. The Role of Chemistry in the Global Energy Challenge introduces some of the challenges of energy research, emphasizing the role of chemistry in dealing with non-fossil regenerative energy. It analyzes the energy challenge in terms of scenarios based on networks of technologies required to convert and store energy.

Chapter 31. Climate Change as a Global Challenge – and its Implications for Knowledge Generation and Dissemination conceives climate change as a global challenge, paralleled by the emergence of both global and local structures in knowledge generation and dissemination. It stresses the need for global governance and discusses the role of local action.

Chapter 32. Toward an Epistemic Web proposes the vision of an Epistemic Web, resulting from a optimization of the present Web for the purposes of knowledge generation and communication. It discusses this vision as well as the obstacles preventing its realization in a broader historical context.

About the Contributors

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Peter Damerow (1939–2011) was a mathematician, philosopher, educational researcher and historian of science. In 1974 he became a research fellow at the Max Planck Institute for Human Development in Berlin, where he worked on the development of mathematics curricula. From 1994 he worked as a research scholar at the Max Planck Institute for the History of Science. His interests lay in the history of science and education, individual and historical development of cognition, the genesis of writing and arithmetic and the history of mathematics and physics in the ancient and early modern periods. In 2010 he developed the idea of an open access, print-on-demand book series, which was then realized as the *Max Planck Research Library for the History and Development of Knowledge.*

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Chapter 1
The Globalization of Knowledge in History: An Introduction

Jürgen Renn and Malcolm D. Hyman

1.1 The Development of Knowledge as a Global Learning Process

Much of today's knowledge, whether scientific, technological or cultural, is shared globally. The extent to which globalized knowledge existed in the past remains an open question and, moreover, a question that is important for understanding present processes of globalization. Considering, for instance, the rapid spread of the wheel throughout Eurasia in prehistory, the spread of Roman law to such diverse areas as the Byzantine Empire and Ethiopia, and the global spread of paradigmatic solutions in architecture such as the Gothic arch, one is led to conclude that a lively exchange existed between cultures in all periods of human development.

In recent years, investigations of the migration of knowledge and comparative historical studies have become active fields of research. With few exceptions, however, the emphasis is placed mostly on local histories focusing on detailed studies of political and cultural contexts and emphasizing the social construction of science. While this emphasis has been extremely useful in overcoming the traditional grand narratives and in highlighting the complexity of these processes and their dependence on specific cultural, social or epistemic contexts, it has also led to an underestimation of the extent to which the world has been connected, for a very long time, by knowledge. The results deliver a rather fragmented picture that tends to neglect the fact that knowledge transmission concerning, for instance, agriculture, architecture, language, writing or calculating, may have been part of long-term and indeed global processes since very early times and can only be properly understood from a more comprehensive perspective.[1]

The central thesis of this book is that, just as there is only one history of life on this planet, there is also only one history of knowledge. Of course, there have been major losses of knowledge and innumerable new beginnings, and there may be as many perspectives on knowledge as there are cultures, if not people who have lived on this planet. But variety, contingency and catastrophic interruptions are also familiar from the history of life. What counts is that both in the history

[1] This has been observed recently also by Sujit Sivasundaram (2010). For recent, more broadly conceived approaches, see (Lloyd 2002; Huff 2003; Ash 2006; Harris 2006; McClellan and Dorn 2006; Costanza et al. 2007; Cohen 2010; Huff 2011; Schäfer 2012). For a general overview of knowledge in non-Western cultures, see also (Selin 1997; Günergun and Raina 2011).

of life and of knowledge, there is a stream of historical continuity with cumulative effects on a global scale, effects that are elusive to predominantly local studies and that account for a highly fragmented, but nevertheless inexorable global learning process, where "learning" is not understood as necessarily indicating progress, but rather as referring to the developmental and evolutionary character of this process, which will be discussed in the following.

1.2 The Role of Knowledge in Globalization Processes

1.2.1 Beyond Economic Globalization

Science in the twenty-first century represents globalized knowledge and benefits from the creation and exploitation of new social and technological structures which enable the global free flow of knowledge and expertise. It could also benefit, however, from a historical awareness of the ways in which techniques and technology in the past have spread throughout the world. The present lack of this awareness hinges on a structural deficit of research in this field due to disciplinary boundaries and fundamental epistemic limitations. This book aims at taking a first step toward overcoming this deficit.

The much-discussed globalization process of the present refers mainly to the economic processes of globalization of markets for goods, capital and labor,[2] whereas the global diffusion of technical innovations and bodies of knowledge is often considered as a mere presupposition or consequence of economic, political and cultural processes.[3] But globalization involves knowledge in more significant ways. Moreover, the globalization of knowledge in the sense of a global interconnectedness of human knowledge is not only a phenomenon of the present age. Our situation today may rather be understood as the result of historical processes that already comprise many dimensions characterizing modern globalization processes, each with its own peculiar constellation of economic, political, technical and cultural means of social cohesion.

Investigating the role of knowledge in these historical processes and referring such an analysis to the present may present opportunities for regaining autonomy with regard to the economic dimension dominating our current perception of globalization processes. An investigation of this kind may indeed explain the sense in which the globalization of knowledge has become a critical dimension of today's globalization processes on which their future development depends. From this perspective, they may turn either in the direction of subjecting the economy of knowledge to the control of other globalization processes, or in the direction of strengthening the autonomy of knowledge and thus its potential for steering such processes.

[2]See, for example, (Ziegler 2008).
[3]For a survey of the current literature on globalization and the role of knowledge and science in it, see chapter 2.

Recent discussions about globalization processes emphasize two apparently contradictory characteristics of such processes: homogenization and universalization, on one hand, and their contribution to an ever more complex and uncontrollable world, on the other.[4] Indeed, the economic power of globally organized transnational corporations increasingly translates into a standardization of mass culture and universal tendencies of wasteful consumption of natural resources. Contrastingly, due to the unequal distribution of wealth, among other factors, the same pressures of homogenization provoke an increasingly diverse spectrum of strategies to cope with these pressures, which leads to an increasingly complex patchwork of social relations. National and regional institutions and traditions in fact play an often neglected mediatory role in filtering and transforming the effects of globalization.

Such observations point to the possibility that the alternative between an increasingly homogenized "flat world" and an increasingly complex network of social relations may be insufficient to capture the dynamics of globalization processes.[5] Evidently, globalization comprises the transcultural diffusion, integration and transformation of a broad variety of means of social cohesion, ranging from goods to language, to belief systems and political institutions. Globalization thus results from a variety of processes, all characterized by the tension between unification and growing complexity.

Economic globalization, for instance, extends the dominance of the world market over local patterns of production and distribution (Wallerstein 1976; Pomeranz and Topik 1999) and, at the same time, provokes counterstrategies for developing diverse local patterns of economic subsistence under the new preconditions (Sahlins 2000). Globalization homogenizes culture and destroys local customs, but it also stimulates morally grounded anti-globalist countercultures, as well as fundamentalism (Robertson 1992). In the field of political decision structures, globalization leads to a growing number of international institutions whose task it is to deal with problems transcending the influence spheres of political institutions of national states (Kratochwill and Mansfield 2006). While globalization thus questions national autonomy from the perspective of global requirements, national integrity is, at the same time, also menaced by a growing tendency toward new regional units (Bowles and Veltmeyer 2007).

1.2.2 Globalization as a Superposition of Various Layers

The contrast between the tendency toward an ever "flatter" and an increasingly "fractal" world (Deleuze and Guattari 2011) suggests that comprehensive globalization processes result from a superposition of various layers, such as the migration of populations, the spread of technologies, the dissemination of religious ideas or

[4] See (Nancy 2002; Sloterdijk 2005; Friedman 2005, 2008).
[5] See (McNeill and McNeill 2003; Friedman 2005; Buchholz et al. 2006; Hofäcker et al. 2006; Mönch 2008).

the emergence of multilingualism. While these processes each have their own dynamics and history, it is their interactions and in particular their involvement of knowledge which marks globalization as we observe it in the present. Considering, for instance, the creation of social identities, it is clear that bodies of knowledge in transition are always carried by agents whose identities are constructed in relation to the knowledge they bear from their place of origin, but also in relation to new kinds of knowledge they encounter in the new space. In the globalization processes of the recent past, with migrations that have rapidly diffused knowledge and behavior (Hoerder 2002), traveling knowledge has had the effect of constantly deconstructing familiar boundaries and producing new identities and solidarities. This pattern of globalization processes is familiar, at least since the age of colonization, and is constitutive of the national and cultural identity of post-colonial societies.[6]

Goods, tools, inventions, suggestions, technical skills and ingenious solutions circulate among human groups with different rates of diffusion, but typically faster than languages, values, traditional rituals, systems of ideas or religious frameworks, and, in particular, administrative and political institutions. These differences in rate account for the characteristic retardation of globalization processes after the realization of their initial incentives. They are, at the same time, indicative of the crucial role of knowledge in these processes.

It is of central importance to observe that goods and the technologies that produce them often spread independently of each other and are each associated with systems of knowledge that make them relevant and accessible to a given culture. The transfer of the knowledge necessary for producing and inventing tools requires, in particular, linguistic capabilities and frameworks of ideas which can only be built up once globalization processes of other types have taken place. Against this background, the crucial role and long history of multilingualism, for instance, going back to ancient scribal cultures, becomes understandable as a critical factor in globalization processes. The relation of the different layers partaking in comprehensive globalization processes is not just one of mechanical succession, otherwise one could be certain that the globalization of markets, for example, implies a globalization of the political system, which is clearly not the case. Rather, the interaction between the various layers may lead to very different outcomes of globalization.

It is generally accepted that knowledge partakes in globalization processes.[7] It even constitutes a specific condition for every form of their realization. On the political level, the spread and improvement of education is considered to be critical for mastering the challenges of globalization, which are constituted as well by the tensions between its different layers. One example is the challenge of mutually adjusting new technologies, on one hand, and traditional behavioral patterns such

[6] See (Feldhay 2004; Lerner and Feldhay forthcoming).

[7] See (Manning 2003; Bayly 2004; Gruzinski 2004; Osterhammel 2009). See also the survey chapter 9.

as learning to handle instruments and machinery by trial and error, on the other. This challenge can hardly be addressed by focusing only on traditional school education.

Globalization processes such as the exchange of technology or migrations of people thus obviously presuppose the diffusion of knowledge: the knowledge of how to deal with the technical means transferred and the knowledge of how to establish life under new circumstances, respectively. Similarly, knowledge is clearly a consequence of globalization processes, just as the exchange of goods or the diffusion of a language also transport knowledge. Knowledge, however, does not just constitute one more aspect of globalization as a precondition and consequence, but represents a critical element of its development. It is in fact the globalization of knowledge as a historical process with its own dynamics that orchestrates the interaction of all the underlying layers of globalization. The globalization of knowledge not only constitutes a relatively autonomous process in its own right, but profoundly influences all other globalization processes—including the formation of markets—by shaping the identity of its actors as well as of its critics.

Accordingly, education is a precondition of globalization processes as well as a consequence of their realization, but the transmission of knowledge through education is only one—and not necessarily the decisive—type of social interaction to determine the development and diffusion of knowledge in globalization processes. It is a central claim of this book that the function of knowledge in such processes cannot be reduced to a precondition or a consequence, neither of which accounts for the emergence of innovations in globalization processes. Rather, the function of knowledge in globalization processes embraces the co-development of knowledge, technology and social interaction. This co-development gives rise to unexpected novelties, such as the origin and spread of writing, the development of printing technology and of the Web, the emergence of social mechanisms for distinguishing knowledge from belief, and the creation of social identities that are structured around the possession of a certain type of knowledge.

1.2.3 Prolegomena to a Global History of Knowledge

In this book, we propose to study the globalization of knowledge in history in this comprehensive sense, from the spread of technological knowledge in prehistoric times to the consequences of the Web for a new economy of knowledge. In the past, challenges such as an unstable equilibrium of population density, the scarcity of nutrition resources, a change in ecological conditions, the emergence of new knowledge or new technologies, or shifts in economic and political power structures triggered phases of intense globalization. One important task of a history of the globalization of knowledge is to identify bodies of shared knowledge that, in these phases of intense globalization, were crucial for the corresponding diffusion and transformation processes. In the following chapters, we deal with the emergence and spread of agricultural knowledge, early key technologies such as ceramics and metallurgy, and with the emergence and spread of writing. But, we are also concerned with the reflective knowledge embodied in religious, philosophical, artistic and scientific traditions, and with modern globalized science, in particular, with models for global knowledge interactions including the mass media and the Internet.

Although a wide range of topics is covered, there is no pretense at a comprehensive history of the globalization of knowledge. Our aim is rather to show, by using examples, how the diffusion of knowledge throughout history can, in principle, be explained in terms of a historical epistemology, paying close attention to the structures of knowledge involved.

A systematic account of the globalization of knowledge in fact has not arisen for two reasons: first, the manifest diversity of data needed, and second, the less obvious lack of a common theoretical language for describing types, media and transmission processes of knowledge. To overcome the first of these problems, we have assembled a number of contributions from various fields, ranging from archaeology and ancient history, via the history of religion and science, cultural anthropology, to the modern natural sciences. Based on these examples, we propose a theoretical framework that is outlined in the following section. Widening the range of examples in future studies will certainly revise some of the general conclusions about the globalization of knowledge that we have tentatively reached in this volume. Our main goal here is to illustrate how such case studies might help in developing a new theoretical language.

1.3 A Theoretical Framework for Studying the Globalization of Knowledge

1.3.1 What Is Knowledge?

A common theoretical language for addressing the issue of globalization of knowledge from a comparative perspective must be both expressively rich and structurally simple. It must draw on established insights from cognitive science, philosophical epistemology, anthropology, archaeology, historical disciplines including the history of science, the history of art and the social sciences; it must moreover encompass the full range of developmental processes implicated in the global spread of knowledge throughout history. No existing academic discipline provides all the tools required.

Knowledge is conceived here as the capacity of an individual, a group, or a society to solve problems and to mentally anticipate the necessary actions. Knowledge is, in short, a problem-solving potential. Knowledge is often conceived (especially in disciplines such as psychology, philosophy and the cognitive sciences) as something mainly mental and private. But from the historical and social viewpoint, it is necessary to consider knowledge as something that moves from one person to another: something that may be shared by members of a profession, a social class, a geographic region or even an entire civilization. From this perspective, knowledge and its movements may be mapped. Shared knowledge is especially important to the artistic, religious, legal and economic systems that constitute cultures; and knowledge travels along with artifacts and artistic styles, myths and rituals, laws and norms, goods and wealth.

Not only is knowledge situated in time and space, but so too is thinking. Recently, the latter phenomenon has come to be studied in cognitive psychology under the term “distributed cognition” (Perry 2003). The work of cognition is not confined to the individual mind but can be distributed among groups of people. What makes this distribution possible are external representations of knowledge such as spoken language, writing and technological artifacts. Through such external representations, knowledge is transported from one mind to another and thinking takes on a social dimension. For example, one may consider how the planning of complex tasks for the construction of the New Kingdom tombs in the Valley of the Kings was distributed among the various workers and craftsmen living in the Egyptian city of Deir-el-Medina, each of whom possessed different skills, knowledge, cognitive abilities and cognitive styles. Or one may consider how Euclid in *Elements* integrated the results of many earlier mathematicians into a complex and novel system: Euclid’s *Elements* thus represent the productive thinking of not just one single man, but of many.

It is typically from external representations that the shared knowledge of a society is, in part, appropriated by an individual (Damerow 1996). The tension between shared and individual knowledge is a fundamental one. It also involves the creative tension between explicit and tacit knowledge that Michael Polanyi discusses (Polanyi 1983). It is only through individuals that new knowledge can be produced, and it is only through societies that it can be reproduced. The differing aspects of the shared knowledge that is appropriated by individuals or groups in a society are closely linked to their identity and self-awareness. I know who I am because I am what I know.

Knowledge has a systemic quality: elements of knowledge are typically part of a network with differing degrees and types of internal organization. This is relevant to knowledge transmission processes because they often involve only the partial transmission of such a network. In some cases, the network may have been transmitted only in fragments, but it may nevertheless still be possible to reconstruct the entire system from them; the reconstruction may, however, also fail or lead to an entirely new system. One example is the earliest attempts at reconstructing ancient scientific theories in the Renaissance from just a few fragments of the classical texts.

Here, knowledge is seen as evolving from individual and collective processes of reflection. Knowledge about things is inseparable from knowledge about knowledge with regards to, for instance, its range, its certainty, its origins or its legitimacy. Knowledge is thus never simply “first-order” knowledge about some concrete or abstract object but always involves knowledge about this knowledge as well, that is, meta or second-order knowledge. This reflexivity of knowledge also accounts for its self-organizing, self-promoting qualities. Second-order knowledge is the origin of curiosity because it involves an awareness of the ever-present limitations of the available knowledge.

The reflection of knowledge presupposes its external representation. Reflection on knowledge is typically a reflection on the external representation of knowledge, as when Euclidean geometry emerged from the reflection on the practice with ruler and compass. As a result, knowledge has a complex layered structure closely tied to concrete forms of representation, ranging from written or iconic representations to social structures or rituals. Also, the articulation and spread of more reflective knowledge follows different patterns than the use and mobility of less reflective knowledge. Thus, knowledge about the existence of artifacts, such as balances, travels much more easily than the knowledge required for their manufacture represented by tools and procedures, let alone the knowledge associated with an abstract concept of weight, represented by written texts.

In the following, we introduce a core set of concepts which are extended and elaborated upon in the survey chapters that introduce each of the four parts of the book. The basic concepts required include a typology of "knowledge forms," "knowledge representation structures" and "knowledge transmission processes." Other concepts we make use of include vehicles for the transmission of knowledge, epistemic networks, knowledge economy, knowledge systems, packages of knowledge, layers of knowledge, epistemic and socioepistemic evolution. Here, we limit ourselves to a discussion of only the most basic concepts.

1.3.2 Forms of Knowledge

Forms of knowledge vary along three basic dimensions: distributivity, systematicity and reflexivity. In terms of distributivity, they range from universal knowledge, acquired in ontogenesis by every human being, to knowledge that is specific to individuals, or shared in social groups, social strata or geographic regions. Knowledge can also be systematized to varying degrees, ranging from isolated chunks of knowledge, via packages of knowledge to more or less coherent systems of knowledge. Forms of knowledge are furthermore distinguished by their degree of reflexivity, which is indexed by the distance from concrete objects manipulated in the course of elementary existence. Reflexivity in this sense is lowest in the case of "intuitive knowledge," that is, unaccompanied by conscious reflection and unmediated by symbolic forms; it is highest in the case of "second-" or "higher-order knowledge," also called "meta-knowledge," where the object of knowledge is itself a form of knowledge.

The range of knowledge forms with different degrees of reflexivity includes the following, strongly overlapping categories:

1. intuitive knowledge
2. practitioners' knowledge
3. symbolically represented knowledge

4. technological knowledge (determined by ends)
5. scientific knowledge (determined by means)
6. second- and higher-order knowledge.

Higher-order knowledge includes any form of knowledge generated by processes of reflection, such as abstract arithmetical knowledge resulting from a reflection on the practice of counting. This classification elaborates on the distinction between bodies and images of knowledge introduced by Yehuda Elkana.[8] In the sequel, second-order knowledge mostly refers specifically to images of knowledge in the sense of that part of the shared knowledge of a society or group that governs its ways of handling and valuing knowledge. This second-order knowledge is also designated as the second-order or epistemic framework of a group or society. Knowledge and second-order knowledge cannot be separated in any absolute way, however, as they always occur simultaneously. Knowledge is invariably part of a system in which it receives its meaning by being related to other knowledge, while this other knowledge, in turn, receives its meaning reciprocally from the given knowledge. As a consequence, knowledge always serves, at the same time, as knowledge about the world and knowledge about other knowledge.

1.3.3 Representations of Knowledge and Knowledge Economy

The mechanisms for the production, dissemination and appropriation of knowledge in a society or group constitute its knowledge economy,[9] dependent on its material culture, on political, economic and cultural boundary conditions, but particularly on its second-order epistemic framework as well. Considered from this perspective, the knowledge economy of a society or group is also designated as its dominant epistemic constellation. Thus, in a theocratic society, its epistemic framework might be constituted by views on knowledge gathered in certain holy writings, while its dominant epistemic constellation includes all the rituals by which this knowledge is disseminated and appropriated.

Knowledge representation structures have been extensively studied in the framework of cognitive science and artificial intelligence focusing on the question of how people store and process information in their minds. An analysis of historical processes of knowledge development and diffusion, however, makes it necessary to extend this notion in two dimensions to cover not only internal but also external representations, and not only individual but also shared knowledge. External representations are the currency of a knowledge economy. They involve the use of knowledge representation technologies ranging in complexity from notches carved on a stick as a simple tallying mechanism to sophisticated

[8] For the concept of images of knowledge, see (Elkana 1981). See also the work of Yaron Ezrahi (1995) on civic epistemology.
[9] See also (Dunning 2000).

computer systems.[10] Understanding how knowledge is stored, processed, disseminated through space and transmitted through history requires taking into account that individual knowledge generally results from the individual appropriation of shared knowledge by reconstructing it from external representations.

For this reason, knowledge representation structures relevant to the processing of shared knowledge are primarily characterized by the interaction of the means of external representation available in a given historical situation with individual cognitive structures such as mental models.[11] The interactional approach requires taking into account the human cognitive capabilities studied by developmental psychology and cognitive science, ranging from intuitive inferences to the reflective construction of semantic networks. It also requires addressing cultural potentials investigated by behavioral, social and historical sciences, such as comparative psychology and linguistics, sociology, economics, ethnology, archaeology and history, in particular, the history of technology, science, religion and art.

1.3.4 Mental Models in the Transmission and Transformation of Knowledge

The history of knowledge has been studied mostly from a restricted perspective that favors innovation over transmission and transformation.[12] Historians of science and technology have often focused on the question of who was the first to discover a fact that later became a key innovation and when this took place. Much less attention has been paid to the question of what role these discoveries or inventions played in the contemporary context of knowledge and how they changed their meaning when transmitted to a different context. What kind of less spectacular knowledge enabled the celebrated discoveries and inventions in the history of science and technology? How was a discovery or invention interpreted by contemporaries? How did the discovery or invention influence the further development of science and technology? What is the relation between the empirical discovery of a fact and its derivation in a theoretical framework? What is the relation between a technical invention and its implementation as a societal innovation? How do transmission processes change the perspective on a technological or cognitive achievement?

To respond to historical-epistemological questions of this kind, an understanding is required of how reasoning operates in frameworks of knowledge that are not mathematized or otherwise structured as a deductive system and that differ even in their conceptual structure from later science. This becomes particularly relevant for understanding globalization processes of knowledge. To account for an important aspect of such types of reasoning, we make use of concepts of cognitive science, in particular of the concept of "mental model." Mental models are specific

[10] This is explored in more detail in chapter 3, section 3.12 and chapter 32, section 32.5.

[11] See (Gentner and Stevens 1983; Damerow 1996; Renn and Damerow 2007).

[12] The following framework is based on joint work with Peter Damerow, see (Damerow 1996; Renn 2007; Renn and Damerow 2012).

types of internal knowledge representation structures that allow inferences to be drawn from prior experiences about complex objects and processes, even when only incomplete information on them is available.

The concept of mental models, as used here, is a particular application of default logic. Default logic is an extension of formal logic that has been developed in cognitive science to account for deductive reasoning as it actually occurs in science, technology and everyday life (Reiter 1980; Parsons 2006). Whereas formal logic requires that the premises of correct inferences already contain complete information about the subject of the reasoning, default logic is based on the principle that inferences from prior experience may always enter the reasoning as "defaults," that is, they are taken to be true as long as there is no evidence available to the contrary. Mental models relate aggregates of knowledge that can be of quite different types, such as data, procedures or other mental models, and of diverse origin, for example, from empirical evidence, from reasonable expectations, from a preliminary hypothesis or implicitly determined by other reasoning processes.

A mental model has a relatively stable structure that connects variable inputs. We use the term "slots" to indicate the nodes in the structure which must be filled with inputs satisfying specific constraints. The mental model of a "machine" for instance, connects slots for a motor mechanism, a transmission mechanism and an operating mechanism.[13] The structure of a mental model may include complex information processing routines that transform the inputs according to the structural relations of the model. Applying a mental model presupposes an assimilation of specific knowledge to its structure. This happens with an "evaluation" of the model, that is, input information compatible with the constraints of the slots is mapped into them. The slot fillers or "settings" may have different origins. They may result from prior experience or prior reasoning (default settings). They may come from input information that has actually been acquired (input setting). They may have been inherited from a "higher-order" mental model when the actual model fills one of its slots (inherited setting). They may be represented by other mental models, procedures or similar knowledge representation structures that may or may not be already evaluated or executed (implicit setting). Or they may result from dedicated procedures that are deliberately executed in real time with the purpose of constructing inputs (constructed settings).

Filling the slots is the crucial process that decides the appropriateness and applicability of a mental model for a specific object or process. Once the mapping is successful, that is, if the input information satisfies the constraints of the slots, the reasoning about the object or process is to a large extent determined by the mental model. Internal knowledge representation by mental models has been proven to be indifferent with respect to the origins of the processed information, that is, the extent to which it stems from input, default, inherited, implicit or constructed settings. We are not dealing here with the question of how in *individual*

[13] See (Marx 1906, part 4, chap. 15).

cognition an appropriate mental model is identified and retrieved from memory, which is an important focus of cognitive science. From the perspective of historical epistemology, mental models are studied with a different emphasis: they are part of a historically transmitted architecture of *shared* knowledge that raises questions not usually posed in cognitive science.

It is possible that more than one mental model is appropriate for application to a specific object or process. In this case, different mental models are linked to each other by the settings of some of their slots to the same inputs.[14] Thus, mental models are challenged by the objects assimilated to them since originally independent domains of reasoning become connected through the object to which different mental models are applied. This may result in complex knowledge representations, but could also lead to insurmountable contradictions. When a mental model does not fit, the object of cognition may be assimilated to another model or the model is modified by accommodation to the new experience. Thus, when Europeans first entered the Americas, they were constantly confronted with the alternative between assimilating their new experiences to known schemes of classification or challenging the schemes themselves, beginning with the very question of whether they had landed in India, or discovered a new world. The application of a mental model to different objects and processes and the outcome of such applications may itself become the object of reasoning that produces knowledge (second-order knowledge). Knowledge about knowledge representation structures may in turn change these structures. Thus, the application of mental models may lead to changes in such models, not only by immediate accommodation in reaction to insufficient fit, but also by deliberate reorganization as a result of accumulated second-order knowledge obtained by reflection.

The concept of a "mental model" is closely related to the concept of a "model" as a corresponding external knowledge representation structure. A material model, for instance a globe as a representation of the earth, supports the use of the corresponding mental model, the idea of a spherical earth, but usually cannot substitute it. A material model is not necessarily active, it does not apply itself to an object, it does not evaluate, and as a rule, it does not even adequately indicate the difference between stable entities, such as its structure, and those that are permanently modified in the process of "running" a model, that is, its use in cognitive processes. For instance, while the material model of a house helps to visualize essential features of an architectural tradition, only its corresponding mental model can guide the actions necessary to build it. The distinction between mental and material models is crucial for a historical study of knowledge development because it provides the key concepts for understanding the culturally determined acquisition, interactive communication and the historical and geographic transmission processes of mental models. Historical epistemology is only concerned with men-

[14] For instance, a steelyard, that is a balance with unequal arms, may be regarded at the same time as a balance *and* a lever, giving rise to a new, combined mental model: the balance-lever model. See (Renn and Damerow 2012).

tal models insofar as they are socially shared models whose material counterparts partake in the knowledge economy of a given social constellation. Cognitive science does not usually deal with social processes, and its concepts and theories only insufficiently account for such processes. This is the reason why we propose the specific concept of "mental models" outlined above for the analysis of historical and geographic processes of knowledge transmission.

1.3.5 Knowledge Transmission Processes

Knowledge may travel with people or it may travel in the form of external representations. These are its vehicles. Various vehicles possess their own peculiar characteristics, such as speed of transmission, reliableness of transmission, and so on.[15]

Spoken language has always constituted one of the chief means of transmitting knowledge. Of special note here are two types of linguistic situations that were as frequent in the ancient world as in the modern: multilingualism and linguae francae. Multilingualism and language contact give rise to phenomena such as linguistic borrowing, where the import of a word from a foreign language frequently evidences the transmission of a foreign concept, and translation, where a text (oral or written) is transferred from one language to another and is inescapably altered (both in form and in content) in the process. Linguae francae constitute a strategic solution to the problem of linguistic pluralism, in which parties agree upon a single language (e.g., Sumerian, Akkadian, Aramaic, Greek, Latin) as common currency; this language can be the mother tongue of only some of the parties. Typically, linguae francae have emerged due to the exigencies of trade, but they also play a key role in knowledge (languages of learning), law (diplomatic languages) and religion (sacred languages, linguae sacrae). But in becoming a lingua franca, not only does a language change its value (in a social sense), but its terms frequently change their value (in a linguistic sense).

The invention of writing created a new and powerful tool for the transmission of knowledge since it enabled knowledge to travel, in both time and space, beyond the immediacy of the speech situation. Writing emerged in ancient Mesopotamia and Egypt, at first independently of spoken language, as a technology for the administration of centralized politico-economic systems. Over time it developed into a tool for durably representing spoken language, or more accurately, the equivalent of spoken language (language that might be spoken), its full potential being discovered only slowly and with increasing usage. With writing came metrologies, calculation techniques, and finally, the rise of the first sciences, which may thus be conceived as resulting from a reflection on the social processes of organizing labor.

Under the rubric of vehicles for the transmission of knowledge, one should not overlook the importance of artifacts that may not have been explicitly intended as representations of knowledge. A technology, or even the rumor of a technology,

[15] For a typology of transmission processes, see chapter 3, section 3.13.

may motivate the (re-)discovery of the knowledge needed to produce an artifact;[16] and careful examination of the artifact may allow one to accomplish what is today termed “reverse engineering.”

Knowledge transmission processes should be studied focusing on the relation between the dynamics of invention and development on the one hand, and the preservation and transmission of established bodies of shared knowledge on the other. All of these processes are determined by diverse media of knowledge transfer, by products, tools and technologies, shared experiences, oral communication, and symbol and information processing systems. Globalization processes such as the geographical dissemination of technologies, the spread of writing, the cultural exchange between Orient and Occident, the colonization and exploitation of cultures, and the creation of global networks of traffic and communication involve specific knowledge transmission processes. Examples are the co-transmission of knowledge and technology, the institutionalized transmission of knowledge by schooling, the initiation of knowledge developments by diffusion, or the reconstruction, adaptation and accommodation of knowledge by reverse engineering. The understanding of globalization processes requires an analysis of the interaction between such transmission processes and the dynamics of invention and development to explain the various forms of globalization, such as the convergence of independent achievements, the optimization, differentiation and adaptation of technologies and ideas, the hybridization of cultural resources and the role of barriers against knowledge transfer.

1.3.6 Epistemic Networks and the Dynamics of Knowledge Development

The transmission of knowledge can be understood as taking place in an epistemic network in which the nodes (or vertices) constitute possessors or potential possessors of knowledge, such as individuals, groups of artisans or scientific communities, and the links (or edges) constitute the routes that knowledge must travel to reach from one node to another. Epistemic networks are not random networks, but rather possess a topology in which certain nodes—termed hubs—are especially important in that they are connected to many other nodes. Thus, for example, while mathematicians and philosophers were scattered throughout the Greek world, certain centers (hubs) were particularly important, such as (in chronological order) Miletus, Athens and Alexandria. The importance of such centers is not unrelated to geographic, political and economic factors. Hence the occurence of cosmological thought in Milesian thinkers such as Thales, Anaximander and Anaximenes is related to the position of Miletus at the heart of Asia Minor, a cultural crossroads to which the cosmological knowledge of the Babylonians would most likely have found its way. Similarly, the wealth accumulated by the maritime empire of Athens, together with the trade and political connections that were es-

[16] Cf. Kroeber’s stimulus diffusion (Kroeber 1940).

tablished, provided the socioeconomic conditions which led to the flourishing of the arts and sciences in the Age of Pericles (Malkin 2011).

Finally, we distinguish between and "intrinsic" and "extrinsic" dynamics of knowledge development. The intrinsic dynamics of knowledge development is characterized by the interaction between knowledge forms and representation structures, triggering processes of reflection which give rise to an increasingly complex knowledge architecture. The extrinsic dynamics is determined by an interplay between epistemic, ecological, cultural, economic and political factors.

The exploration of the consequences of a given system of knowledge in a given social and cultural context and its subsequent restructuration may serve as an example for an intrinsic development, such as, in the European context, the elaboration of the Aristotelian system of knowledge and its subsequent transformation into modern science during the early modern period (Damerow et al. 2004). The transfer of a given system of knowledge in a process of colonization to a new natural and cultural setting may serve as an example for an extrinsic development. Intrinsic and extrinsic developments may be closely intertwined. Extrinsic (i.e., societal) contexts may be transformed into conditions for the intrinsic (i.e., cognitive) development of knowledge systems (e.g., the role of democracy for the prospering of science or the role of colonization processes for the development of biological and medical knowledge), while the intrinsic evolution of knowledge systems may become an extrinsic factor of knowledge globalization. The possibility of colonization processes, for instance, may depend on achievements of intrinsic knowledge developments, such as progress in astronomy or navigation techniques.

All knowledge traditions are local traditions in the sense that they depend, at least at their origin, on specific contexts, specific groups and specific ranges of knowledge, as well as on a specific history determining its architecture in an ultimately contingent manner. Globalization of local knowledge traditions involves intrinsic as well as extrinsic developments, potentially enhancing their social dominance, their range of application and their degree of reflexivity or, alternatively, destroying their autonomy and reducing their complexity. The globalization of local knowledge has thus to be conceptualized as a crossover phenomenon resulting from the integration of local knowledge traditions whose initial encounter depends primarily on a specific constellation of dominance, resources and knowledge potentials, that is, on an extrinsic dynamics, while their subsequent co-development is also shaped by an intrinsic dynamics.

The globalization of local knowledge is typically accompanied by a localization of globalized knowledge in the sense of the recontextualization of an alleged universal system of knowledge which may trigger its restructuration. Thus, as a rule, the implementation of globalized scientific knowledge in new contexts has not just taken the form of an application and specification, leaving its intrinsic structures unaffected, but has yielded instead a hybridization of globalized and local knowledge, changing the overall history of knowledge, even with regard to the initial constellation of dominance, resources and knowledge potentials.

1.4 A Historical Outline of the Globalization of Knowledge

This book represents a test case for the possibility of a large-scale comparative history of knowledge. Is it possible to draw general conclusions, beyond a compilation of disciplinary insights, about a subject as vast as the processes of knowledge transfer and transformation from the beginning of human history until today? To offer a definitive answer, one would obviously need many more case studies than we could assemble in this volume and an even greater effort at integrating their results. Yet, from the extensive discussions among the authors, which have accompanied the preparation of their contributions since the initial Dahlem Conference in 2007, some preliminary conclusions could be drawn which justify further research in this direction. From the perspective of the editor of this volume, some of these conclusions are summarized in the introductory surveys to the four parts of the book (chapters 3, 9, 16 and 24). These preliminary conclusions mainly aim to encourage innovative forms of cooperation that bridge both cultural and social history and also theoretically guided comparative approaches. The relation of our discussion on the recent literature on globalization is reviewed in chapter 2.

1.4.1 From Technology Transfer to the Origins of Science

Part 1 of this book explores a series of processes in the very early phases of globalization, from the transmission of practical knowledge to the emergence of science. It is normally assumed that the growth of knowledge in early history is merely an outcome of innovations, such as the development of sedentariness, the invention of new technologies including ceramic and metallurgical production, the introduction of a redistributive economy, the emergence of the state and the origin of writing. Here, we show that the history of knowledge is a layered history, where more recent knowledge builds on successive layers of older knowledge in such a way that the outcome of a knowledge production process becomes the precondition for the stability of the level of development attained. We are thus dealing with a self-referential process of knowledge generation and dissemination. For example, the invention of writing in Mesopotamia was originally a consequence of state administration. Not only did it change the conditions of the geographical transfer and historical transmission of knowledge, but it also extended the human cognitive facilities by stimulating reflection processes and the creation and articulation of previously unknown mental constructions. Eventually, writing was converted from a consequence into a precondition, not only for a particular model of state organization, but for a level of socioeconomic development depending on these novel mental constructions, from literature to science.

Science initially emerged as a mere by-product of sociocultural evolution, as a reflection on the material means of human interaction with nature outside their immediate contexts of application. Mathematics, for instance, emerged in ancient Babylonia when the material means of organizing human labor, such as accounting systems, became an object of intellectual exploration in the context of teaching these systems to specialized scribes. Science emerged independently in different places in the ancient world. The globalization of science in the sense of an exchange of systems of theoretical knowledge across large distances, for instance within the wider Mediterranean world or East Asia, also goes back to classical antiquity. Due to economic and political circumstances, however, this exchange remained limited and episodic without the combination of accumulation and autonomous diffusion of scientific knowledge characteristic of more mature phases of globalization.

While in the polycentric world of Europe, the Near East and India, exchange did indeed take place among cultures as diverse as ancient Babylon, Egypt, Greece and India, a continuous accumulation of scientific knowledge beyond local networks, such as Hellenistic society, was prevented by a scattered urban landscape with only a few hubs of economic and epistemic trading, as well as by the scarceness and fragility of institutions dedicated to the production and transmission of such knowledge.

In contrast, such an accumulation of theoretical knowledge did take place in the relatively monocentric world of China beginning with the Qin Dynasty, resulting in a system of knowledge deeply embedded within and limited by the practice and ritual contexts of state administration and, in this form, also diffused to Japan, the Korean peninsula and South-East Asia.[17] This determining context of knowledge production and transmission would also serve for a long time to come as a strong selective filter for the appropriation of new kinds of knowledge so that, for instance, new astronomical knowledge relevant to state rituals would be continually assimilated to the traditional knowledge system, whereas the system resisted the appropriation of new technological knowledge that might have had labor-saving effects, but no immediate significance for state administration.

The strong dependence of the dynamics of the development of knowledge in antiquity on local economic, political and ideological factors was, both in the East and the West, due to the fact that the networks supporting knowledge generation and exchange were centralized in the sense of being dependent on all-important centers that constituted potential critical points of failure. While even the exchange of knowledge between the two extremes of Eurasia, which were connected by trade routes, may not be excluded, it can only have played a marginal role because of the very network of weak ties of epistemic networks in antiquity. In summary, even the ancient world was subject to a globalization of science that remained, however, episodical.

1.4.2 Knowledge as a Fellow Traveler

Part 2 of this book deals with the dissemination of knowledge in the sequel to that of power and belief structures on the Eurasian continent. It thus studies knowl-

[17]See, for example, (Schottenhammer 2007). Comparing the China Sea with Fernand Braudel's narrative of "Mediterranée," Wang Gungwu argues that "the China Sea did not have a history that was comparable to the intense exchange of peoples, goods and ideas that characterized the Mediterranean" (Wang 2008, 7–22). See chapter 11 and also the discussion in (Malkin 2011).

edge as a fellow traveler, its transmission being largely governed by an extrinsic dynamics. Yet this transmission of knowledge also involves an intrinsic dynamics, strenghtening the significance of knowledge as it proceeds, for instance, by stimulating the creation of new media and new institutions for its transmission. A special role is played by such all-encompassing belief systems as the world religions. Their self-contained and self-organizing qualities enabled them to challenge the authority of political powers, to outlast their initial reference states and to significantly contribute to a globalization of knowledge. They also offered long-lasting epistemic frameworks guiding the selection, appropriation and accumulation of knowledge. At the same time, religious systems are constantly challenged by new knowledge.

In the European case and in contrast to the case of China, the tradition of religion to challenge the authority of the state contributed to create the conditions that allowed science to challenge the authority of religion. In China, scientific knowledge received its ultimate justification from its constitutive role for the state. The role of scientific knowledge in a particular society thus depends on the dominant epistemic constellation, which is determined by shared epistemic frameworks such as religions as well as by political, economic and cultural boundary conditions. As long as scientific knowledge is merely a fellow traveler of other societal processes, its survival often depends on transient resonance effects with the dominant epistemic constellation. Only when science in turn affects the dominant epistemic constellation, as happened in early modern Europe, does it lose its ephemeral status, initiating an intrinsic dynamics of the globalization of science.

Religions have been one of the most important conveyors of the globalization of knowledge and of science in the period between antiquity and the early modern era. With the rise of Buddhism in India and of Christianity and Islam in the West (as well as Judaism after the destruction of the Second Temple), religion became decoupled from the state to a previously unparalleled degree, emerging as a source of authority separate from and potentially in conflict with that of the state, thus developing a potential for global spread (world religions). This new development set the stage for the accumulation and transmission of knowledge which, while nonetheless always extrinsically motivated, would neither be confined to local networks nor be inseparable from immediate contexts of application, and thus free to be repurposed or translated to new contexts.

The extent to which this possibility was realized remained largely contingent on the emergence of a social network that supported the production and dissemination of knowledge. Hubs in this network were typically flourishing trade or religious centers, or capital cities of large empires. Structurally speaking, an empire may be characterized by a limited number of hubs with many links and a large number of locales (in terms of network nodes) with few links, and often with only a single link to a hub. As to the longevity of knowledge accumulation within such networks, it is their high interconnectivity that prevents knowledge growth from being limited by the ephemeral fortunes of local centers, as knowledge travels easily and is no longer dependent on a single center. In sum, traveling is a way of preserving knowledge. Empires further facilitate the wide-range diffusion of knowledge and, in particular, the integration of knowledge emerging from different hubs. But they are not the only social structures with such properties, as the global infrastructures of the world religions could and indeed did serve the same function over extended periods of time.

1.4.3 From Knowledge as a Fellow Traveler to the Globalization of Modern Science

It was only in the densely connected urban landscape of early modern Europe that a self-reinforcing mechanism connecting the production of specifically scientific knowledge with socioeconomic growth arose, driving combined globalization processes of science and economy. The combination of epistemic and economic globalization by a feedback loop with an inbuilt tendency to scale up is the hallmark of the globalization of modern science. In this period, a class of highly mobile scientist-engineers emerged who were concerned with the resolution of military and technical problems on behalf of various, mutually competing patrons (Renn 2001).

Medieval and early modern science had been able to cross political and cultural borders, also because of its use of Latin as a lingua franca. But when Latin as a scientific lingua franca became increasingly complemented by the development of scientific traditions in the vernacular, the vertical (social) mobility of science and its practitioners also increased.[18]

Also, the availability of cheap writing materials in Renaissance Europe made a huge difference for both the social and the spatial mobility of knowledge. In the past, technical knowledge had been confined to groups of specialist practitioners and separate from traditions of theoretical knowledge such as the Aristotelian tradition. The new scientist-engineers were involved with practical problems and assimilated the knowledge of practitioners; at the same time they worked within frameworks of theoretical knowledge, which caused them to reflect upon practical knowledge. This reflection led to the equilibration of practical and theoretical knowledge that gave rise to modern science.

Ultimately science is reproducible and transportable, not because of any methodological principle, but because it focuses not on ends, which tend to be more localized, but on means. In addition, it was recursively decoupled—albeit never completely—from its original contexts by an ever longer chain of representation and reflection. But the practice of science in the early modern period, as in antiquity, was initially bound to specific local contexts, such as courts or certain urban centers on which its individual practitioners depended for their support. Due to the association of science with a socioeconomic transformation process, however, it emancipated itself from its immediate contexts by creating institutions

[18] This process is studied in (Burke 2004). The importance of the simultaneous use of Latin and a vernacular language for multilingual communication is highlighted by Alix Cooper (2007).

of its own and a network of communication extending across Europe, its colonies, and even to Asia. As a consequence, science was decreasingly bound to social and geographical contexts. It no longer constituted an exceptional social phenomenon depending on favorable circumstances and was increasingly freed from immediate, context-dependent practical purposes, as was characteristic of traditional medicine or astronomy.

In the early modern period, all the patterns of the globalization of science had essentially already formed within the European network of scientific knowledge.[19] Indeed, the early modern period saw a massive diffusion of scientific knowledge within Europe, fostered by the spread of universities, academies and educational institutions, producing not just literacy, but a particular curriculum contributing to the creation of a canon of scientific disciplines.

The successful expansion of science within Europe created a model essentially followed by all later globalization processes of science, including the replication of institutional settings and canons of knowledge. The thus emerging network of scientific knowledge exhibited self-organizing behavior, as is evident in the fact that there was no central control of scientific practice, and yet scientific knowledge accumulated at an astonishing rate and traveled quickly across the scientific community.[20] The growth and mobility of scientific knowledge resulted from a network in which most scientists were in contact with only a few other scientists, but there were a few scientists who were in contact with very many scientists, acting as network hubs. This network possessed these same connectivity properties at the level of institutions sponsoring and promulgating scientific knowledge, such as courts, religious societies, the homes of wealthy patrons, universities and the newly founded scientific societies. Again, most institutions had direct relations with only a few others, but a small number of institutions were hubs with numerous direct connections. The presence of such similar structures at the levels of individual scientists and of institutions engaged in science illustrates the properties of self-similarity and scale-freeness. Positive network externalities fostered the inherent dynamics of spreading science so that the more people engaged in it, the more useful it became.

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[19] Toby Huff places strong emphasis on institutional and social conditions for science, on the one hand, and its metaphysical underpinning, on the other. The latter aspect leads to rather narrow criteria for distinguishing modern science from other types of science, while the former tends to isolate the social conditions of science from the more general knowledge economy in a given society. This focus on modern science rather than a more general focus on knowledge risks neglecting the long cumulative history of the globalization of knowledge and the introduction of Eurocentric bias, giving an a priori partiality to specific cultural and social conditions prevailing in Western Europe (Huff 2011, 14). Among the favorable conditions for science, the author, following Max Weber, emphasizes the Protestant Reformation and the associated literacy.

[20] The role of the "république des lettres" is discussed in (Rüegg 1996, 20–52). Lorraine Daston distinguishes the "république des lettres" and the modern "scientific community" (Daston 2001, 151). Jakob Vogel and Ralph Jessen analyze more closely the differences between the "république des lettres" and the national character of science organization in the nineteenth century (Jessen and Vogel 2002).

From the eighteenth century, science began to be organized in well-defined disciplines, each with a canon of concepts, procedures and methods at the center of relatively stable and institutionally embedded knowledge systems. These knowledge systems had resulted from an earlier period of knowledge integration and reorganization, which led to their stabilization. This process had centered on isolated challenges, such as the challenging objects of earlier modern engineering, which now turned into the paradigmatic objects of disciplinary science. It had been a key experience of the early modern period that the world could be manipulated by recognizing its intrinsic laws. Initially, this experience was effectively limited to a few, particular fields of knowledge, such as mechanics. But it did give rise to the hope, constituting the core of the Enlightenment ideal of science, that this limitation could be overcome by the development of a universal scientific method, thus establishing scientific rationality once and for all and independently from the contigencies of local contexts.[21]

This transcendental, universalist understanding of science became a major factor in its globalization, often justifying the introduction, in a top-down manner, of a “scientific method” into domains where the cognitive prerequisites in the sense of a prior integration and stabilization of knowledge had not been established. The limitations of this approach, however, became visible even in the earliest attempts to naively transpose the principles of such pioneering sciences as mechanics to other such fields as chemistry and biology, let alone to the social domain. In the course of history, the failures of the transcendental, universalist approach to science and its implementation have contributed to the generation of numerous “anti-rationalist” movements, from Romanticism to religious fundamentalism. These failures, however, also helped to develop a non-universalist understanding of science, exposing its deeply historical nature, but also the role of local knowledge for its development.

1.4.4 The Place of Local Knowledge in the Global Community

The different consequences of the encounter between local and globalized knowledge are dealt with in Part 3 of this book. In some cases, local knowledge systems have been irrecoverably extinguished by globalization processes in rather a short time. On the other hand, there are cases in which local knowledge has been synthesized with or at least partly defended against the influences of the global community. Although local knowledge may seem to be in retreat, it continues to be relevant, even today, for mastering such primary living conditions as food production, medicine, architecture, mobility, but also for preserving cultural identity. In addition to its double function for practical and cultural purposes, it may take the form of second-order local knowledge, shaping the generation, transmission and application of knowledge in local contexts. Such meta-knowledge tends to

[21] For a comprehensive study of the Enlightenment, see (Israel 2001, 2006, 2010, 2011).

remain implicit and is sometimes only expressed in terms of social practices, such as the organization of learning processes.

Here we claim that the role of second-order local knowledge is much more central than is usually admitted. Traditional second-order local knowledge is often less affected by changes of technology, environment or new information than is first-order knowledge and is therefore less easily rendered obsolete. At the same time, new forms of second-order local knowledge may emerge from the encounter between local and globalized knowledge. Such newly emerging local second-order knowledge, however, is itself conditioned by the global history of knowledge, and in particular by the legitimacy in a given historical situation of different epistemic perspectives, one globalized, the other local. Local knowledge played a crucial role in the differential development of non-Western countries. The variability of local conditions continues to foster the diversification of knowledge, even in the presence of globalization. The impact of this diversification of the globalization of knowledge, however, remains limited unless new forms of representation become available that allow this knowledge to be shared and made useful for shaping globalization processes with an increasing awareness of their local conditions and consequences.

1.4.5 The Globalization of Modern Science

To assess the relevance of an investigation of historical processes of globalization for the present situation, Part 4 of this book is dedicated to the great challenges faced by humanity today when dealing with knowledge. These challenges are partly consequences of sociocultural evolution, such as the climate and energy challenges, and in particular, of the powerful knowledge that has accumulated during this evolution, such as the exploitation of fossil fuels. Dealing with the consequences of such unplanned, global experiments with our planetary system seems to require more knowledge than can be produced by the dominant modes of knowledge production of sociocultural evolution. Current economic and technological challenges may require in particular the development of new diffusion models in which knowledge is recognized as an explicit transferable.

One example is provided by the widely discussed need for an alternative to the current energy distribution system, which is not sustainable and will not meet future needs. Although free market economy is the only system available for regulating the global energy system, it has failed to adequately regulate the energy system since local prices largely do not reflect global costs. Alternative energy markets may regulate not only the flow of energy, taking into account knowledge about resource scarcity, but also the flow of knowledge itself in such a way that energy production and distribution is optimized.

We thus face an emergent process, socioepistemic evolution, in which the global production of ever more and increasingly diversified knowledge about humanity's interaction with nature becomes crucial for its survival. In this process, political developments do not merely shape the conditions of knowledge diffusion, but policy-making regarding these global challenges depends critically on the generation of new knowledge and knowledge-based assessments. In Part 4, a variety of pathways toward a socioepistemic evolution are analyzed with regard to the coupling of social and political developments and the global diffusion of knowledge.

1.4.6 Socioepistemic Evolution

In conclusion, let us summarize the larger historical framework in which the globalization of science is taking place. Modern science represents the third in a series of monumental revolutions, at the same time social and epistemic, that have affected humankind since the sedentary revolution of the Neolithic. The first was the rise of the centralized state, as for instance in Mesopotamia, where technologies allowed for reflection on practical knowledge that enabled completely new methods for the organization of labor. The second was the birth of the world religions, which challenged the authority of the state and ultimately transcended the limits of the state. Modern science, in turn, came into conflict with the authority of religion. This conflict was not one of complete opposition, but one of differing intrinsic dynamics.

Religions comprised and continued to accumulate a vast amount of knowledge, integrating it into overarching worldviews that closely connected knowledge of the natural and the social worlds; at the same time religions exerted powerful control over the totality of knowledge. Modern science, while open to expropriating much of the knowledge previously controlled by religious authorities, contested not only key elements of this knowledge, but also the authority of religion to control knowledge. From the dialectics of this conflict, science gave birth to new worldviews, rivaling that of religion, and eventually to a new social order. The commonality of the three revolutions lies in the increasingly autonomous status they achieved for the production and dissemination of knowledge, and in the increasing potential for application of this knowledge to the control of society.

This series of three revolutions ultimately resulted from a cascade of nested evolutionary processes building upon the foundation of biological evolution. Sociocultural evolution began somewhat before the emergence of modern humans. The precondition for sociocultural evolution was the evolution of a rich social intelligence aimed primarily at cooperation; the biological correlate of this development is the appearance of the neocortex.[22] The central dynamics of sociocultural evolution is the transmission of material and social culture. This mechanism facilitated the transmission of knowledge between individuals, allowing humans to shape their environment and to acquire new capabilities at a rate that is many times faster than the pace of biological evolution. Acquired knowledge was thus easily transmitted across generations.

Sociocultural evolution led eventually to the emergence of the state: the first of the three revolutions. With this revolution we see, on the one hand, the creation

[22] For a recent discussion of the onset of sociocultural evolution, see (Bowles and Gintis 2011).

of means for the external representation of knowledge which not only increased the durability of knowledge, but also permitted reflection upon the knowledge represented. This resulted in new second-order knowledge. On the other hand, the new possibilities for labor organization opened up by administration practices that were dependent on media for the external representation of knowledge, led to radical material changes for individuals, further facilitating sociocultural evolution. It was especially important that new distributions of labor liberated certain individuals from work directly concerned with their survival, thus allowing them to engage in more abstract activities of knowledge production.

The emergence of the state dramatically accelerated sociocultural evolution by allowing for an increase in the production of knowledge and offering technologies, such as writing, for the transmission of that knowledge across space and time. Qualitatively new sorts of knowledge were able to develop in this context, as for example, Babylonian science or Greek philosophy. Knowledge could now spread faster, whereas before, the spread of knowledge was essentially limited to the speed of demic spread. While items of knowledge can and indeed do travel, entire systems of knowledge hardly travel during this phase, owing to their essentially local character. Moreover, the weak links between hubs of knowledge production severely impeded the travel of knowledge. Nonetheless, with this revolution we see the first major advance in the globalization of knowledge.

The next major advance came with the second revolution, the emergence of world religions, which provided the kind of efficient networks for spreading knowledge that were missing in the earlier phase. The world religions embodied much of the structures of authority and of the mechanisms for knowledge production and dissemination of the state, but whereas knowledge in the state was limited by its geographic boundaries, the packages of knowledge associated with world religions traveled more or less freely across state boundaries. The world religions in effect constituted superstructures built upon existing social orders. They challenged the authority of the state and in a number of cases states responded to this challenge; witness, for instance, the Roman persecution of Christians. In any case, religion offered a new social order greater than that of the state, but modeled on the state; thus, for instance, the concept of the Umma in Islam and the City of God in Christianity. At the same time, the world religions could adapt; for those who adopted them there was—and is—an equilibration of traditional beliefs and the beliefs constituting the new religion. While authority was merely asserted by the state (and grounded in physical force), the world religions needed to justify their authority. Thus they developed sophisticated schemes of justification and produced extensive bodies of knowledge through complex processes of dialectics. Some of these schemes and processes had their origins in earlier systems of thought that had arisen under specific local conditions, such as Hellenistic philosophy. But whereas such schemes and processes had been local, the world religions embedded them in institutions of potentially global extent. It is against the background of these complex schemes of argument, processes of justification and elaborate bodies of knowledge—and in dialogue with them—that modern science was born.

Modern science, the third revolution, eventually gave rise to an entirely new form of evolution. Just as sociocultural evolution was grounded in biological evolution, so this new form of evolution—socioepistemic evolution—is grounded in sociocultural evolution. With each new evolutionary process in this cascade, the preceding ones eventually become dependent on the subsequent layers. Thus, the continued existence of our species in a biological sense becomes dependent on sociocultural evolution once the latter has reached a global extent, and, with the globalization of science, our survival becomes dependent on socioepistemic evolution. Socioepistemic evolution is a process even more rapid than sociocultural evolution. It is as a result of this process that our environment has changed more in the past one hundred years than in the entire period that hominids have existed. Science is a self-organizing network that inherently scales globally. It has created conditions for accelerated social evolution, including economic conditions, which favor the further development of science. Thus science actually creates the conditions for its own propagation. In socioepistemic evolution, continuity is provided by the transmission of the means of science and the material culture of which they are part. Socioepistemic evolution is an evolutionary process in its own right, which begins when knowledge production and dissemination have attained autonomy, having become ends in themselves, and when this autonomously produced knowledge has a global impact on the human condition.

The evolution of scientific knowledge itself exhibits all the dynamics characteristic of an evolutionary process that we refer to as "epistemic evolution."[23] Epistemic evolution is nested within socioepistemic evolution, constituting one of its driving forces. The exploration of the inherent potential of the means for gaining knowledge gives rise to a variety of alternatives within a knowledge system, corresponding to mutation in biological evolution. In an advanced state of its development, these variations lead to internal tensions and contradictions, resulting in the transformation or the branch of a new system; this is speciation. Differing material and cognitive contexts create ecological niches for epistemic evolution. Various forces of selection apply. Since socioepistemic evolution is ultimately grounded in biology, its greatest selective force is human survival. But this ultimate selective force is, of course, mediated through many layers of culture and society that impose diverse proximate forces of selection on epistemic evolution such as compatibility with prior knowledge, coherence and experimental verification, but also non-scientific constraints such as prestige, compatibility with non-scientific ideologies, fashions and so forth, which may differ in their effective exploitation of social intelligence or of resources within a given ecological niche of a scientific system. But whatever the details of the dynamics of socioepistemic evo-

[23] For earlier attempts to conceive the history of science as an evolutionary process, see (Hull 1988), and the first edition (1991) of (Damerow et al. 2004) which draws on (Damerow and Lefèvre 1981) and (Damerow et al. 1991).

lution may be, it is evident that its challenges for humanity can only be mastered if the conditions for epistemic evolution are optimized to deal with these challenges, providing science with both serendipity and relevance. Ignoring these challenges could lead to scholasticism, while streamlining science for specific purposes could lead to missed opportunities for innovation.

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Chapter 2
Knowledge and Science in Current Discussions of Globalization

Helge Wendt and Jürgen Renn

2.1 Introduction

Recent studies of global history and the history of globalization have, among many other subjects, dealt with issues of knowledge and science. In the following, some of these studies will be examined from the perspective of a history of the globalization of knowledge. From this perspective, several key questions arise. First and foremost: what role is knowledge considered to play in the concert of other factors of globalization?[1] Frequently, globalization studies place economic, political or cultural developments in the foreground. The second question is how knowledge is considered to interact with these other factors. The third question concerns the relationship between knowledge and science. How is this relationship understood in recent histories of globalization? And how can an understanding of science biased by the European tradition be overcome? The fourth question concerns the dynamics of knowledge development: how does knowledge change over long historical periods as they are covered by recent studies of globalization? These studies trace the change of economic activities, governance, trading and transport. But what do they assert about the global history of knowledge?

As the studies considered in the following do not aim primarily at a history of the globalization of knowledge or science, the aspects concerning knowledge and science have to be filtered out from the overall account and examined for their importance in the narrative as a whole. In the following, the historical studies covered in this chapter will be briefly presented. They will then be examined for the role that knowledge and science play in them. Next, the role assigned to Europe in these studies of globalization will be reviewed. Finally, the historical periodizations underlying these studies will be analyzed with a focus on the understanding of capitalism and Industrial Revolution they present.

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[1] See also the introduction to this volume, chapter 1.

2.2 Major Contributions to a History of Globalization

The Birth of the Modern World by Christopher A. Bayly (2004) is one of the most celebrated works in global history of recent years.[2] Focusing on a long nineteenth century, from 1780 to 1914, the author develops his idea of global modernization. In his view, this was not initiated unilaterally by movements proceeding from Europe to other parts of the world. Rather, it constituted a phenomenon that was established by the worldwide exchange of information, the major political configurations of the colonial empires, and by politicized social movements. Christopher Bayly takes the history of science seriously, attributing to it an important place in the global history of the nineteenth and twentieth centuries.

In the reception of Bayly's work, this aspect of *The Birth of the Modern World* has, however, remained largely ignored. Next to the "major" themes of the economic reconfiguration of the world by capitalism, the great religious movements or the decimation of the indigenous population of the Americas, the aspects of Bayly's work that are related to the history of science have not been taken up in subsequent historical discussions. Neither Kenneth Pomeranz (2006) nor John McNeill (2005) mention this subject in their reading of Bayly's work. Gauri Viswanathan (2005) touches the theme in his review, dealing with Bayly's critique of Foucault's role of the state. Viswanathan also discusses the issue of non-religious systems of reason. But even in this review, the topic of science is rather neglected as part of the global modernization process. Thus, Bayly's treatment of the concept of knowledge in global processes has met with little substantial response.

In *The Birth of the Modern World*, Bayly discusses the form of history known in German as *Ideengeschichte*, and in English as "intellectual history." Traditionally, this historiography was strongly oriented toward Europe and North America. It has taken on a truly global dimension only after paying increasing attention to the history of science. Emphasizing this role of the history of science in broadening the historical perspective, Bayly points out:

> An exception to this rule is the history of science. Historians of science have recently found much more room for the dynamic role of Asians, Africans, and other non-European peoples in the creation of the hybrid bodies of learning by which global society understood the natural world. They have also been quite successful in explaining how preexisting assumptions and styles of intellectual training guided people's reactions to new scientific ideas coming to them from the West. (Bayly 2004, 285)

In this, Bayly clearly presumes that scientific knowledge comes primarily from Europe. Transported by colonial regimes, with the help of imported school systems

[2] See (Conrad 2004).

and public debate, non-Europeans had the opportunity to partake of this knowledge. In the colonies, even more strongly than in the countries of origin themselves, the sciences entered into a symbiosis with the political currents of liberalism and socialism. This symbiosis also changed the spectrum of themes covered in the individual sciences. According to Bayly, science is thus an important indicator that enables the historian to identify global debates as well as to reveal processes of change and dissemination, as will be shown in more detail below.

Similar to the definition of knowledge in the present volume, in *Verwandlung der Welt* (Transformation of the World) Jürgen Osterhammel defines knowledge as "cognitive resources that serve to resolve problems and master life situations in the real world" (Osterhammel 2009, 1105).[3] For Osterhammel, modern science, as it emerged around the mid-nineteenth century, represents a significant rupture with European origins and had a global impact. The new subjects of science, their designations and the social type of the scientist are clear signs of the rupture and of the autonomy of the corresponding social system. Another factor was the emergence of more and more specialists, who became increasingly involved with state governments and with enterprises. In Osterhammel's opinion, by the end of World War I the institutionalization of scientific knowledge had been completed in most European countries and in the United States. This geographical focus of institutionalization on areas of the so-called "West" represents for Osterhammel an undeniable fact that also a more encompassing global history would not be able to overturn (ibid. 1105–1107). In short, Osterhammel does not consider the emergence of the system of science in the West as the result of intricate historical processes of globalization, as is the case in the present volume, but rather characterizes it as a Western event of global significance. In contrast, Bayly sees the "Western" sciences as being clearly shaped by non-European experiences.

An entirely different argument is advanced by Andre Gunder Frank, who in 1998 undertook a broadly based attack on Eurocentrism, focusing partly on issues related to history of science, while his overall perspective is governed by economic issues. Since the 1970s, he had been part of the study group investigating world system theory and the expansion of European capitalism. In his study *ReOrient. Global Economy in the Asian Age*, he claims that in the worldwide capitalistic economic system no single power ever reigned supreme, nor did a hegemony ever emerge from processes of globalization. According to Frank, the same holds for European technology:

> The received Eurocentric mythology is that European technology was superior to that of Asia throughout our period from 1400 to 1800, or a least since 1500. Moreover, the conventional Eurocentric bias regarding science and technology extends to institutional forms [...]. (Frank 1998, 185)

[3]See also the introduction to this volume, chapter 1.

For this reason, he turns against two opinions frequently expressed in accounts of global history. First, according to Frank, the Scientific Revolution cannot be conceived as a prerequisite for the European Industrial Revolution, as will be discussed in more detail later. Second, a one-way transfer of knowledge from Europe to other parts of the world, by means of goods, institutions or ruling systems, never took place. Instead, the history of knowledge transfer has always been multi-directional. It began much earlier than European expansion and continued to be multi-directional, even during European colonialism and imperialism.

Walter Mignolo's *Local Histories/ Global Designs. Coloniality, Subaltern Knowledges and Border Thinking* of the year 2000 continues the tradition of relativizing Europe's role in the history of the world. He poses the question of how thinking can be decolonized and sets out on a quest to find alternative philosophical traditions to "colonial/modern" thought. In his view, this "colonial/modern" thought developed in the sixteenth century, first in Spain and then, as the center of the European world system shifted, in the Netherlands and in England, and finally, in North America (Mignolo 2000, 30). Since the Enlightenment, this "colonial/ modern" philosophy, which Mignolo terms "occidentalism," became the decisive Western way of thinking. In his study, Mignolo attempts to uncover alternative and local histories, as well as other layers of knowledge and ways of thinking, and their relations to dominant occidentalism:

> So knowledge from local histories where intellectual projects are produced at the intersection of silenced and silencing languages, [...] did not receive the same attention. This situation is not trivial. It opens up a space for the multiplication of interconnected projects at the intersection of local histories and global designs, both at the 'center' and the 'periphery'. (ibid. 71)

Mignolo distinguishes two layers of global history: the first layer comprises the global history of European expansion. In the second layer, a variety of local situations persist. Mignolo sees in their manifold the potential for a new, systematic and non-hegemonial approach that he terms "border thinking."

In *Les quatre parties du monde. Histoire d'une mondialisation*, Serge Gruzinski also focuses on the Spanish expansion. He discusses the Spanish sphere of influence in the sixteenth and seventeenth centuries, paying particular attention to the role of actors who created and attested to globality. His study may be characterized as a cultural history of globalization that also covers processes of knowledge exchange. Gruzinski perceives the Iberian colonial globalization as being distributed over many locations where knowledge of equal value emerged in all important domains, as is also stressed by Francisco Bethencourt (2005) in his review of the work. Gruzinski cites the example of the spread of Aristotelianism in the Spanish empire:

> The process of globalization thus did not see the light of day at a certain location of the [Spanish] monarchy. It is not bound to the Iberian

> peninsula or to the European continent, because Aristotelianism and allegorical and symbolic languages can be discovered just as well in Mexico as in Salamanca. (Gruzinski 2004, 369)

The reception of Gruzinski's book clearly concentrates on issues of knowledge. In his review, de Neymet recognizes the fundamental importance of the category of knowledge for Gruzinski's depiction of a mestizo globalization emerging in the Iberian sphere of influence (de Neymet 2005).

Gruzinski argues that the foundation of universities and other educational institutions should not be understood as expressing Westernization or occidentalism. The very production of knowledge at the University of Mexico or at the various colleges of the colonial cities shows that certain institutions of knowledge had a global character from the start. They then spread globally throughout the Iberian domains and were transformed according to local contexts. Gruzinski makes this movement of knowledge between different intellectual centers and across global and local scales especially clear using the example of Aristotelian commentaries that were written in different parts of the world.

Peter N. Stearns's study *Globalization in World History* deals with the historiography of global history and undertakes an attempt to identify future topics in global historical research. Although his emphasis is generally on economic topics, "technological, sociocultural and political forces" are not neglected (Stearns 2010, 1). Knowledge and science are not listed here, but the book makes it clear that they are considered as part of the areas of technological and sociocultural forces. The basis of Stearns's argument is that every area of human thought and activity is affected and influenced by globalization processes, even when they seem to be merely characterized by local circumstances (ibid. 2). On the first pages of his book, Stearns develops a brief definition of globalization: "Looking at globalization as the accumulation of different types of connection helps to focus the relationship of current developments to the past" (ibid. 6). Globalization history is the history of connections and relations and as such can be traced back to early history.

In an even more explicit way than Stearns, John and William McNeill establish in *The Human Web* that human history is the history of increasing connections: "A web, as we can see it, is a set of connections that link people to one another" (McNeill and McNeill 2003, 3). This history of connection building is to be understood as occurring in a broader frame of human history, as "[...] human history is an evolution from simple sameness to diversity toward complex sameness" (ibid. 322).

In this chronologically structured study, knowledge is one of the components of human history that serves as evidence for the evolution of an increasingly extended network among people. The study begins with prehistory showing that, with the exception of Australia, the bow and arrow spread throughout the world and ends with a discussion of the newest communication technologies. The authors focus on connections shaped in contexts of wars and rivalry which are reinterpreted as moments of exchange. Relevant connections are distinguished according to whether they were directed toward the exterior of a given society or whether they emerged from the internal organizations of social entities. According to the authors, internal communication and cooperation are fundamental for explaining the superiority of one group over another (ibid. 4–5).

2.3 Knowledge and Science in Narratives of Globalization

Traditionally, science has been associated with literacy. In many of the non-European regions studied by global history, no indigenous traditions of writing existed so that in the older historiography, the knowledge there was conceived as being inferior to European knowledge. In post-colonial studies, this perspective was contested and characterized as being Eurocentric and elitist.[4] Against this background, it becomes important to trace how the individual authors define science and knowledge and how they contextualize them in different cultures.

Christopher Bayly's position on this issues can be best understood in connection with his discussion of the evolution of political thought. At the beginning of the chapter "Theory and Practice of Liberalism," dealing with colonial movements inspired by European liberalism in the nineteenth century, he introduces the topics of liberalism, revolutionary thought, liberal economic theories and theories of political systems. Bayly reconstructs how newly emerging political entities imported packages of knowledge and linked them to so-called traditional forms of knowledge. Bayly identifies this form of knowledge evolution as a way of expressing new forms of nationalism in different historical situations, as happened in the classic revolutionary states of the United States and France, but also in the context of the Meiji "Restoration" of Japan and of the Egyptian nationalist movement. More specifically, he points out:

> The intellectual leaders of these Asian and Middle Eastern movements also mixed elements from modern Western radicalism and theories of human rights with claims to defend ancient traditions of community and the honor of the land from the rising tide of global commercialization, most powerfully manifested in the Atlantic economies. (Bayly 2004, 288)

Here, Bayly represents a view of history that radically rejects a Eurocentric modernization paradigm. For Bayly, modernization has ceased to be European but rather emerged in relation to traditional ways of societal organization and political thinking. He simply declares any existing and dynamic social, political or technical phenomenon in any part of the world from the beginning of the nineteenth century to be modern. As news and information could be received worldwide, any individual standpoint unavoidably developed in relation even to distant

[4] See, for instance, (Harding 1998).

events. Bayly stands in a tradition of historiography that has broken fresh ground since the 1960s. It takes its distance from the assumption of radical revolutions and rather sees revolutionary movements as being rooted in intellectual constants (ibid. 287–288).

Bayly stresses these constants and long-term developments in historical processes with the intention of understanding the history of political theories in close connection with the history of scientific discoveries. He considers the separate study of politics and science to be misguided and simply an artifact of disciplinary specialization. This separation obscures, according to him, the close relation and interactions between political and scientific spheres. For Bayly, science occupies a special place in the world history of the nineteenth century: "... [S]cience was as influential in the mindset of the nineteenth century as religion had been during the Renaissance." (ibid. 312)

He characterizes science as an approach to reality that in many ways used to be more radical than political theories. In particular, he claims that simultaneously throughout the world science developed into a subsystem of society and increasingly became the foundation on which political power and decision-making were based. Bayly makes use of a broad concept of science that includes the natural sciences as well as sociology, history and ethnology. According to him, during the nineteenth century all subjects of knowledge underwent a similar development throughout the world and eventually became university disciplines.

For Bayly, this development from knowledge as a collection of unspecified skills to science as a societal subsystem comprised three phases. The first phase was the creation of huge pools of knowledge, such as museums and archives. He also refers to the surveying and classificatory enterprises of natural history undertaken by Linné, Goethe and Alexander von Humboldt. These European enterprises, however, were not solitary undertakings but had their counterparts in the creation of herbaria and other collections in Africa, India or China, establishing, for instance, the basis for local medical knowledge. In the second phase, individual efforts were pursued to identify unifying principles, while the third phase saw the establishment of a comprehensive evolutionary theory by Darwin and others.

The essential factor accounting for the rapid development of European sciences was the commitment of nearly all governments to invest in specialized administrative units and infrastructures that supported science, as well as in technical resources like the railroads. The precision and reliability of scientific claims associated with government institutions allowed them to enhance their legitimacy, which, in turn, led to increased investments in this system by the state (ibid. 313–315). In the course of this process, science, now established in complex institutions, became in Bayly's analysis a globally communicable achievement that turned into an instrument of persuasion relying on cultural and scientific traditions in each country (ibid. 323).

For Osterhammel, educational institutions are important factors of global history. Only during the nineteenth century did school curricula develop into the form of systematically structured courses of instruction implemented by public and private institutions. In Prussia, whose educational system became a model for other states, schools were part of the state ideology and played an important role in transmitting the official ethics of the state. In colonial regions, only a very limited number of European schools were established. In Algeria under French rule, an educational dualism of French schools and Koran schools prevailed. In China, Japan and the Ottoman Empire, the adoption of European forms of knowledge transmission was intensely discussed around 1900, but were realized only to a limited degree. It was predominantly Western, especially missionary organizations, that implemented schools recognized by Europeans as valid educational institutions (Osterhammel 2009, 1129–1130):

> The schoolification of society was a European-North American program of the early nineteenth century, which over time was elevated to a goal of state policy worldwide (ibid. 1131).

According to Osterhammel, this approach assumed a programmatic character when states recognized that educational policy was instrumental in asserting their own claims to power in three areas of society: in the socialization of the state population; in its political formation; and in the storage and propagation of knowledge (ibid. 1131).

Over the course of the nineteenth century, European universities achieved a new quality. While in many other countries outside of Europe, institutions of higher education often took the form of academies or professional schools, in the West universities became sites of research and even of new political thinking. According to Osterhammel, well into the twentieth century, non-European institutions diverged widely in quality; their performance was hampered by the limited spectrum of subjects taught, the lack of a complete academic curriculum, and a staff often selected more on the basis of colonial power hierarchies than achievement. Osterhammel stresses, however, that there were also non-European institutions such as the University of Istanbul founded in 1900, the University of Tokyo founded at the end of the 1870s and the Academia Sinica founded in 1928, which broke with conventional educational institutions in their countries and significantly contributed to science—as measured against their European models (ibid. 1132–1139).

Osterhammel also considers the development of universities within Europe, starting with the establishment of the German research university. This became a model that was adopted in England, France and, towards the end of the nineteenth century, also in the United States and Japan. The context of this development was competition among rival nations (ibid. 1142–1146).

Turning to the broader issue of knowledge, Osterhammel discusses the situation of the "world languages" in the nineteenth century, tracing their diffusion, forms of usage and stability. He regards language as an important medium for knowledge transfer and examines for the Ottoman Empire, China and Japan the close connection between the adoption of European languages and the introduction of European knowledge. He compares the openness that made these innovations possible to the considerable resistance of European educational systems with regard to the exclusion of non-European languages and subjects from their curricula. He ascribes an important emancipatory role to the spread of colonial languages—even in their creole and pidgin forms—since they not only served colonialist purposes but also enabled individuals to pursue their personal goals (ibid. 1112–1115).

The concentration on the nineteenth century unavoidably emphasizes the developed European schooling and academic systems that Osterhammel considers as being superior to non-European educational systems. For him, science is an essentially European concept that becomes globalized over the course of the nineteenth century. But he also recognizes other facets of the globalization of knowledge, in particular, its increasing diversification as well as the role of non-European knowledge in other domains.

Stearns approaches the issue of knowledge diffusion and scientific practice with an entirely different emphasis, reflecting on the role played by individuals. He emphasizes that, in the transfer of knowledge, contexts and convergences are much more important than single actors. He cites the examples of bronze smelting, the compass, gunpowder and, somewhat surprisingly, of the printing press in Europe. For Stearns, the individual "inventor" always stands in a long line of tradition. He leaves the question of the relation between science and new technology largely open and mainly speaks generically only about knowledge. Only when he deals with the second half of the twentieth century does his grid become finer when he discusses, for instance, the way laboratories collaborate with each other to conduct research on global epidemics (Stearns 2010, 149).

In Stearns's understanding, knowledge emerges over longer periods of time and through long enduring connections. One of the systems transporting knowledge is religion. Contacts between religions, as well as the propagation and mixing of religions, were especially important in the period of European expansion (ibid. 77). Nevertheless, in the actual globalization of the twentieth century, religions are losing importance as agents of the globalization process; instead of developing a common language they highlight their mutual differences. This common language has instead been created by science with its collaborations and cooperation in laboratories, and even more so by the global language of the global culture of consumption (ibid. 150–153).

In contrast to other studies that point to the increasing centralization of the world, John and William McNeill pursue another view of history, emphasizing a persistent pluricentrism: over the course of the centuries, the world has been permanently transformed into a tight network of connections. Consequently, any multiplicity of languages, lifestyles, manners of dress or political and legal systems that may have existed is being replaced by a few, globally asserted norms. During this process, a world emerged with a comprehensive information infrastructure, characterized by constant competition, along with a continual process of mutual perception, urbanization and migration that led to a reduction in cultural varieties. This process is taking place while systems that are already globalized penetrate traditional ones. Nevertheless, John and William McNeill stress their assumption of a pluricentrical world by pointing out that in history no hegemonial center ever existed. In a world assembled by a global network, they observe the emergence of counter-religions and counter-systems—for example as competing ideologies—that embody and pursue global multiplicity (McNeill and McNeill 2003, 270–274).

This development is not restricted to politics, culture or economics: over the course of the twentieth century, science has seemingly become a monolithic system in which the same scientific doctrines are taught in the same way throughout the world. The point of departure for this development was the formation of disciplines during the nineteenth century. John and William McNeill nevertheless claim that science, like all other social systems, is ultimately characterized by pluricentrism. To justify this view, they point to the fact that science is by no means limited to universities and research laboratories. For one thing, it has entered into a close partnership with the development of technology, where it becomes substantially application-oriented and immersed in an industrial context. What is more, science at the same time represents a kind of countermovement, because—at least in the authors' liberal view—it has adopted some of the moral authority of religions (ibid. 277–279). Science today is embedded within the economically defined model of competing companies. Here, economic knowledge and application-oriented science are highly dependent on each other; each is governed by the mechanisms of the global systems of economics and science.

Walter Mignolo stresses the distinction between science as it was shaped by European determination in the colonial and modern era, on the one hand, and non-European knowledge viewed from the perspective of "subaltern studies," on the other. These subaltern studies were first employed by Indian historians to describe actors and agency in Indian colonial history from below, that is, from the perspective of the lower social strata of colonial society. Taking up the concept of subaltern studies, Mignolo claims that individuals and groups opposing colonial regimes existed throughout the world, creating forms of knowledge that he characterizes as "border knowledge" since it served to break up the boundaries set by colonial and modern science (Mignolo 2000, 11–12).

"Border knowledge" refers quite generally to archives and movements of knowledge directed against occidentalism. Mignolo is less interested in institutions or in the question of whether one tradition of knowledge was more important than another. He rather concentrates on broader cultural issues such as language, clothing and pop culture. It remains an open question whether the promise that border knowledge holds as an alternative knowledge system to "Western" science can actually be fulfilled. For Mignolo, knowledge and science are in any case situated in two largely separate spheres communicating with each other only in a relationship of politically determined historical correspondence.

Parts of Serge Gruzinski's book *Les quatre parties du monde* can be read as a kind of response to Mignolo. In contrast to Mignolo, Gruzinski conceives Spanish colonialism not as overwriting distant continents with occidentalism, but rather as the creation of a space in which global communication became possible, vividly illustrated by the propagation of literature (Gruzinski 2004, 55–59) and of printing workshops (ibid. 62). The space to which Gruzinski refers of global communication opened up by colonialism becomes particularly visible when he traces how knowledge recorded in the colonies was utilized in Europe. He discusses its intellectual and commercial impact on European countries (ibid. 62–69), on the one hand, and reconstructs the processes by which knowledge was adapted in Mexico, Peru and the Philippines, on the other. Gruzinski points to a global space of mutual perception: events that took place on one continent were received, written down or immortalized in images shortly thereafter in another part of the world. The assassination of Henry IV in Paris in 1610 was described some months later in a diary written by a Mexican mestizo. Similarly, the naval battle of Lepanto, where the Spaniards fought against the Ottomans, soon appeared as a motive on a Japanese screen (ibid. 14–19).

Gruzinski cares less about the difference between science and knowledge. He defines science as the efforts toward systematization that were recorded throughout the globalized Spanish Empire from the sixteenth century on. What matters to him is the framework in which knowledge could emerge. He investigates the sites and the people through which it came into being as well as the reception that this emerging knowledge received. On the one hand, colonial global knowledge is based directly on the "Ancients," that is, on Homer, Aristotle, Ptolemy and other ancient scholars and philosophers. On the other hand, their works constitute the framework for structuring the genuinely different knowledge about the newly discovered worlds outside of Europe. Referring to this formative role of the ancient knowledge, Gruzinski explains the references to Plato and Ptolemy integrated by Diego Muñoz de Camargo in his *Relaciones geográficas*, as well as André Álvares de Almada's need to classify Africans as cannibals (ibid. 204–205). Such texts saw a worldwide circulation and thus constituted the foundation for every form of discourse and classification undertaken in the colonial world.

Knowledge was collected and classified in natural histories, herbaria and compendia of navigation maps. Since experience played a central role in these works, indigenous people or mestizos in the colonial areas could contribute significantly to European knowledge on the basis of their own experiences. Experience and the claim of having seen what is described or depicted became an increasingly important argument in its own right and legitimized new knowledge (ibid. 211). For Gruzinski, knowledge and science are intimately related. He also stresses that knowledge was not only represented by texts, but also recorded in images. He refers, for instance, to frescos created by indigenous artists in Mexican monasteries, which not only represented a blend of artistic techniques, but also integrated knowledge from Europe, Asia and America.

2.4 Revisiting Europe from a Global Perspective

Since Dipesh Chakrabarty in 1992 called for a provincializing of Europe, most global historians endeavor to avoid the impression of Eurocentric argumentation. In view of the colonial and imperial, and then of the international political and economic dominance of the "West," historians face a great challenge. One solution to this historiographic challenge is to enlarge the temporal focus and to emphasize the historical eras before European colonialism, because then European dominance in the areas of economics, the organization of politics, and the production of knowledge did not exist.

Another argumentative strategy is to draw attention to local non-European processes that changed European knowledge systems, even in the heyday of colonialism and imperialism. Marshall Sahlins has shown, for example, that the development of capitalism was different in China, Hawaii and Vancouver Island (Sahlins 2000). This in turn then raises the question of whether this development took place in the same way in the heartlands of industrialization: in Manchester, Lille, Philadelphia and Essen. In a certain sense, capitalism is comparable to the global development of knowledge, as both are dynamic and complex systems.

A third historiographical current responding to the challenge of post-colonial critique emphasizes the role of constant negotiations among different groups. It recognizes the asymmetry created by European dominance, but insists on the idea that power and knowledge are in flux due to these ongoing negotiations. All of these historical accounts, like the contributions to the present volume, stress the role of local contexts and point to events and circumstances of global history that had hitherto been neglected by the dominant narratives.

According to Christopher Bayly, the superiority of science and its larger historical tradition have been propagated in Europe at least since the beginning of the nineteenth century. But he also emphasizes that debates about science and its history did not just take place in Europe and that science was part of many societies worldwide. As a result, a global communicative space emerged over the course of the nineteenth century in which science was an independent subsystem. He presents arguments against a European origin of science, as they were brought forward in India and the Arab world, pointing to the autonomy of the scientific traditions of these regions and their achievements (Bayly 2004, 317).

Bayly pursues the debate about the "origin" of science up to the end of the twentieth century, arguing that what ultimately counts historically is not the provenance of a scientific insight, but its application. Accordingly, he focuses on the various societal environments in which science was performed. In particular, the environments of European and North American industries provided opportunities and ideas that shaped the further development of science because they offered multifarious areas of application. For Bayly, the appeal of earning economic benefits by way of scientific and technological inventions prevailed over any idealist expectations associated with science. He notes that in the nineteenth century Europe had started with certain "advantages" because its dynamics resulted from a politically and economically fragmented landscape that had developed over centuries. A high number of territories competed intensely with each other and were thus compelled to constantly innovate their technology as well as their methods of organization, especially in warfare. Bayly believes that the fact that European societies from the the eighteenth century on were highly technologized and militarily oriented may have situated them to offer more stimuli to Asian states than could have happened in reverse, since the latter enjoyed conditions of relative peace (Bayly 2004, 80–81).

In order to correct the unilateral image of a European dominated nineteenth century, Bayly pays special attention to those institutions in non-European countries that worked in a systematic and application-oriented manner comparable to the European situation. He considers the examples of the Ottoman Empire's School of Languages and of the emerging scientific community in Japan. He mentions, in particular, the role of seismology in Japan and the transfer of medical knowledge from the West to Japan, China, the Arab world and India. For him, this knowledge transfer is indicative of the openness of these knowledge systems to external influences and to their awareness that their own history had involved borrowing components of knowledge from various sources.

Political reasons and in particular a situation of global competition and rising nationalism could lead however to a closure of knowledge systems with regard to each other. In the Islamic regions and in Africa, for instance, Bayly identifies "hybrid systems" in which traditional and Western treatments existed and developed in parallel; they were highly competitive and always concerned with their demarcation (ibid. 318– 320). According to Bayly, this was a worldwide development. While some of these "hybrid systems" can be traced back to European origins, their unfolding can only be understood as taking place in reaction to local contexts. The global development of science must also be seen in this context. Europe was no exception. Science with its characteristic specialization and standardization emerged at the same time in many regions of the world and had to struggle everywhere with "traditional" approaches in fields like medicine, agriculture and small industry. This struggle was comparable to any other process in which new knowledge was generated and had to compete with existing traditions. There was hence no a priori reason to expect that science would enjoy higher acceptance than any other new knowledge (ibid. 320–322). European expansion and the spread of science did not in fact lead to a complete and sudden rejection of knowledge prevalent in the colonized countries. For the most part, this knowledge was merely recontextualized and so placed within a new global consciousness from which it drew its meaning and had to prove itself.

According to Osterhammel, a global consciousness provides a framework that encourages the capability of societies to engage in self-diagnostics with regard to their current situation. In his view, the nineteenth century was "a period of enhanced self-reflection" (Osterhammel 2009, 1279). The sciences in general, and disciplines such as history or sociology in particular, served as instruments that enabled simultaneously occurring phenomena to be diagnosed in an interwoven global context. Obviously, the issue of self-reflection is not limited to the domain of science, but rather raises the more general question of what modernity means and whether it could mean something different in different cultural contexts. In this regard, Osterhammel observes that such self-reflection hardly took place before 1900:

> Indeed it is difficult to find independent and distinctive Indian, Chinese, Middle Eastern-Islamic or African paths for the period between around 1800 and 1900, which provided a counterpart of their own to the hegemonial Western European model of modernity. Such differentiations did not become noticeable until after the turn of the century, initially more in terms of intellectual history than structure. (ibid. 1279–1281)

Two formulations by Osterhammel are interesting in this context: first he claims that "colonialism and globalization [created] cosmopolitan orders of language" (ibid. 1116). Yet, according to his understanding, expansion, disseminations or mixtures are not motors of globalization and perhaps not even indicators, but mere consequences. The second interesting formulation is connected with the reforms of writing undertaken in many countries with the goal of bringing elite language and the vernacular closer together. Osterhammel denies that these projects reflected "a direct imitation" of Europe (ibid. 1117). These projects are rather to be explained as a consequence of the given "national" situation. Osterhammel covers alphabetization and literacy comprehensively. He interprets these topics as belonging to the competition among nations for modernity, described in terms of the rising rates of literacy in the population. In this competition, the northern European states, the United States and Japan came out ahead of, for instance, Mexico or China. Osterhammel discusses at length what he considers to be missed educational opportunities in the nineteenth century in these countries (ibid. 1125–1127).

Osterhammel argues that curricula and research topics as they were shaped by newly created national institutions were largely immune to the influence of non-European experiences. Instead, they developed their own research agendas and methods independently of such influences. However, some of their research results were translated and thus reached non-European scholars as well. This transmission happened not by chance, but rather in response to specific demands for new knowledge emerging among growing scientific communities, for instance, in China and Japan. This transmission was hampered by considerable obstacles, however, in particular by the cultural connotations of key scientific concepts. Osterhammel concludes:

> More than ever before and more than since, say, the mid-twentieth century, in the long nineteenth century the flow of knowledge around the world was a path down a one-way street." (ibid. 1151)

As a consequence of the Western habit of ignoring or rejecting knowledge recorded elsewhere, the European sciences took on a hegemonial status. This status was reinforced by the growing professionalization of the sciences in Europe and the formation and differentiation of disciplines that gave rise to scientific achievements serving as milestones for global science over long periods of time (ibid. 1147–1156). Such claims may seem to suggest that Osterhammel is merely rolling out a new edition of a Eurocentric historical account. Yet, the author actually attempts to straddle the two main currents of global history without coming down as either a "diffusionist" or an "evolutionist." Osterhammel works in both directions: as we have seen, while university models were diffused, the development of national languages emphasized each country's own character.

Gunder Frank takes a position opposite to that of Osterhammel: He rigorously denies that anything like a "European technology" even exists. After all, Europe has always been dependent on external influences. Even the innovations developed during the colonial period were based on a mutual, albeit asymmetrical, exchange of knowledge (Frank 1998, 204). In the picture he draws of the world prior to 1800, Frank emphasizes the economic features. According to him, China represented the most powerful economic sphere of influence, followed by Japan and India, with Europe lagging well behind. In any event, these are the four main global players of his account, which neglects Africa and Latin America and leaves North America somewhat surprisingly in the background. Frank also denies the existence of any long-term hegemony. For him, neither the use of gunpowder for firearms, nor the construction of ships, nor the invention of the printing press or of mechanized textile production, nor innovations of metallurgy or of other areas of mining and transport constitute the basis for any enduring superiority of one political-economic system over another. He rather traces temporary phenomena of dominance lasting for limited periods of time and covering only restricted geographic spaces. According to Frank, these cannot be explained in terms of knowledge, but always depend on economic circumstances (ibid. 193–203):

> That is, technological progress here *and* there, even more than institutional forms, is a function of world economic 'development' much more than it is of regional, national, local, let alone specificities. (ibid. 186)

Walter Mignolo's goal is to provide a common theoretical and epistemological basis for the flows of politics, ideas and knowledge in the world system of border knowledge that is at the center of his analysis. Border knowledge consists in demarcation, in opposition, and in a process of separation from occidentalism. Mignolo connects his broad theoretical approach with the dependency theory developed in Latin America. Dependency theory analyzes why and how Latin

American economies were for a long time unable to disengage themselves from power relations as well as from societal and economic structures inherited from the colonial period. For Mignolo, this theory provides an example of how colonial and modern thought can be overcome with the aim to put an end to the Latin American states' imitation of Europe (Mignolo 2000, 54).

According to Mignolo, capitalist and colonial domination continue to persist. They are opposed by processes of detachment which Mignolo believes to constitute an ongoing political project. These processes of detachment do not simply correspond to reactions to the colonial world, but are composed of both older and more recent layers of collective experience and thinking (ibid. 50). For Mignolo, the capitalist world system proceeding from Europe, Europe's colonial dominance and the system of knowledge developing through Europe's experience abroad cannot be divorced from each other. They determine the economic and scientific system of thought to such a degree that, even in the aftermath of the colonial and modern epochs, an alternative system of thought can be achieved only under one condition. Such an alternative system has to rely necessarily on those traditions of thought that did interact with the systemic colonial dominance, but that nevertheless remained recognizable as independent traditions and striving themselves to mutate into new systems:

> The reordering of the geopolitics of knowledge manifests itself in two different but complementary directions: 1. the critique of the subalternization from the perspective of subaltern knowledge [...]; and 2. the emergence of border thinking [...] as a new epistemological modality at the intersection of Western and the diversity of categories that were suppressed under occidentalism (as an affirmation of Greco-Roman tradition as the locus of enunciation in the sixteenth and seventeenth centuries), Orientalism (as an objectification of the locus of the enunciated as 'Otherness'), and area studies (as an objectification of the 'Third World,' as producer of cultures but not of knowledge). (ibid. 95)

In this sense, global connections play a central role for Mignolo. They explain the dominance of the colonial and modern system and also harbor the potential for the creation of alternative systems. In contrast to occidentalism, the alternative systems do not aspire to hegemony, but are always countermovements and third paths, based on multi-local substantiations and are thus oriented toward the dissolution of fixed blocs (ibid. 95).

Instead of trying to filter Europe out of global processes, Serge Gruzinski advocates integrating Europe into the world events of the seventeenth century. There is no denying that Spain, as a part of Europe, spread throughout the world, and that there were strong tendencies to centralize knowledge. But the Iberian peninsula was by no means the node through which all threads of knowledge ran. In contrast to Mignolo, Gruzinski does not assume that occidentalization can be equated with the development of hegemony. He makes this clear by using the example of Aristotelianism, which for Gruzinski could not achieve any hegemony in the non-European world but remained simply one conceptual framework among others.

It was Europe that suffered because of the dominance of Aristotelianism: there it prevented any significant influence of non-European knowledge on science. By dint of the export of Aristotelianism as a knowledge system comprising books, professors, the mastery of the Latin and Greek languages, as well as the foundation of new monasteries and universities in Spanish America, Europe believed to have achieved hegemony with regard to any other form of knowledge. In Mexico, Aristotle was taught as early as 1553 in a local Dominican monastery, that is, even before the university was founded. The Thomistic interpretation of Aristotle's work played an important role in Iberian globalization. As a consequence, the Aristotelian *Organon* became the foundation for all studies at the colonial universities. Since the Iberian social context of reception was similar to that in Europe, scholars in the colonies did not develop different interpretations from those familiar in the colonial homeland. This is also why Western philosophy did not receive any new impulses from the colonies (Gruzinski 2004, 340–332). So far, Gruzinski's account represents a typical narrative of the expansion of European knowledge to another continent.

Then, however, Gruzinski develops his argument in a surprising direction. He claims that this belief in European superiority was actually part of a European self-deception in the early modern period. Key to this self-deception was what Gruzinski calls the "Aristotelian bubble" (ibid. 355), that is, the Aristotelian scholastic legacy which largely determined the way in which any knowledge and experience were interpreted; interpretations departing from this dominant view were persecuted (ibid. 245–256). With a few exceptions, this Aristotelian bubble made Europeans largely blind to the innovations and the new knowledge produced in the colonial sphere that went far beyond the scope of Aristotelian teachings. Gruzinski discusses attempts by Europeans to integrate non-European knowledge, such as the reception of Chinese nautical knowledge by Bernardino de Escalante or of Chinese medical knowledge by Juan González de Mendoza. He notes, however, that characteristically, such alien knowledge later fell into oblivion (ibid. 350–355).

In conclusion, at the beginning of Iberian globalization, various knowledge traditions coexisted in relative autonomy with respect to each other. According to Gruzinski, however, this autonomy was gradually undermined by the export of thought systems like Aristotelianism, by translation activities, by the spread of publishing ventures and, more generally, by the global diffusion of knowledge overcoming geographical separations.

Peter Stearns sees hegemonial situations emerging, for instance, from trade and shipbuilding. In general, in the literature on globalization, shipbuilding is mentioned frequently since ships are highly technical products which could be used for conquest and expansion. Furthermore, shipbuilding was an important medium for the exchange and the accumulation of knowledge. Through war and expansion, technical knowledge passed from one side to the other, at least as long as it could be matched with existing technical and epistemic concepts.

Stearns analyzes hybridization processes associated with trade and shipbuilding. Through Arab trade, two different techniques of shipbuilding spread in the Indian Ocean, namely the Arabic and the Malay-Chinese traditions. He shows how a specialized terminology of shipbuilding spread over large distances (Stearns 2010, 36–37, 60–61). He also discusses the role of trade relations for the spread of the compass from China, via the Arab world, all the way to thirteenth-century Europe, as well as for the spread of the astrolabe and the cartographic and narrative descriptions of geography (ibid. 38–39).

The spread of knowledge is not at the focus of Stearns' interest however. He rather uses the occurrence of similar technologies in different locations as evidence for the existence of intensive trade relations that must have been responsible for the exchange of these technologies (ibid. 44). As it turned out, eventually Europeans benefited more than others from this exchange. Thus, Portuguese shipbuilders produced results superior to those of their Arab forerunners once they equipped their newly-built ships with cannons.

Stearns deals not only with the question of which area of knowledge might bear potential for a hegemonic position. He is also interested in intercultural histories of knowledge such as the history of the concept of zero and the history of firearms. In particular, he shows how the concept of zero emerged and was spread as the result of an adaptation of knowledge in various historical situations. He emphasizes the non-linear and even controversial character of its history. In parts of India, the concept was rejected and once it arrived in Europe, a considerable length of time passed before it generally prevailed. Yet, it had scarcely entered the European chambers of commerce before it was carried, by way of European expansion, to other continents where it soon became firmly established (ibid. 47). Several centuries later, a similar intercultural development eventually led to the dominance of firearms in fifteenth-century Europe (ibid. 58–59). Stearns gives further examples that show how European superiority depended on external influences and, in particular, how the resulting superior technology became decisive for European dominance and how it finally led, from ca. 1850, to true globalization.

2.5 Capitalism and Industrial Revolution as Controversial Milestones of Globalization

In the history of the last centuries, the economic system of "capitalism" played such a central role that also studies of global history focusing on issues other than economic can hardly avoid taking its historical development as a reference for periodization. Similarly, industrialization as a new mode of production established since the end of the eighteenth century became a central historiographical category for globalization studies. Capitalism and industrialization were traditionally considered to be merely European historical processes that achieved a certain impact in other parts of the world. The works of Immanuel Wallerstein and Eric Hobsbawm widened the perspective on these crucial developments to a global scale, insisting on the worldwide network of interconnections that made them possible, although Europe continues to play a central role in their narratives. Their works in fact constitute the first steps toward a history of capitalism and industrialization emphasizing the dependency of these processes on the relations between Europe and other parts of the world. This explains why their pioneering contributions have become standard references for any history of globalization.

By outlining a global history of capitalism, Wallerstein suggested a modified reading of European colonialism. He considers the development of European capitalism as a process in its own right, which only initially depended on European political expansion. This economic development extended over a large period of time and correlated core regions, peripheries and semi-peripheries into a single world system. The European global economy was distinguished from other economic systems by creating "a single division of labor but multiple polities and cultures" (Wallerstein 1979, 6). This European global economy was based not primarily on colonial and imperial hegemony, nor was it determined by individual actors, nations or governments. Rather, the economic system was the arena in which these actors and powers could play their roles.

The European global economy in fact distinguishes itself from other economic systems by the high degree of connectivity between its participants. Once the pre-Spanish economic systems of America had been incorporated into this European system through colonial conquests, a global European economic system emerged, whose core region shifted, by the mid-seventeenth century, from the Iberian peninsula toward Flanders and England. But even apart from political conquests, the European world system expanded and involved ever more regions, such as, for example, the Ottoman empire (Wallerstein et al. 1987).

The Industrial Revolution is generally seen as an important step in the development of capitalism. Eric Hobsbawm designates this developmental step, which began around 1800, as "capitalist industrialization" in order to distinguish it from more traditional modes of production. He situates the Industrial Revolution within a context of various social and technological developments. These are not restricted to England, let alone to Europe. According to Hobsbawm, capitalist industrialization "was part of a larger network of economic relationships, which included several "advanced" areas, some of which were also areas of potential or aspiring industrialization [...]" (Hobsbawm 1999, 13). Wallerstein and Hobsbawm have transformed the issues of capitalism and industrialization into themes of a global historiography. They thus prepared the ground for more specific historical studies investigating the global connectivity associated with social and economic processes.

In the tradition of this economic historiography, Christopher A. Bayly identifies historical milestones associated with economic changes. He claims that societies all over the world changed in multilayered global processes, moving from proto-globalization through archaic globalization toward modern globalization.

The latter was prepared by what he calls "industrious revolutions," taking up a notion introduced by Jan de Vries. Bayly follows the development of modern globalization through "the great acceleration" of imperialism, nationalism and liberalism up to 1914. A key theme of his work is the development of networks comprising a "multitude of centers, a global history of connections and interconnections" (Bayly 2004, 44–46; 451–467).

A new perspective that he introduces in his study concerns the role of changes in the labor process over the course of the nineteenth century, which he claims to be more fundamental than changes in production processes as they are highlighted by the term "Industrial Revolution." Bayly employs instead the concept of *industrious revolutions*, introduced in the singular by Jan de Vries for developments in North-West Europe between 1650 and 1850 (DeVries 1994, 49–55). For the nineteenth century, Bayly traces instead how workflows changed all over the world and how work itself became an appreciated value.

According to Bayly, the industrious revolutions did not have their exclusive origin in Europe, but rather constitute an important example of how distributed processes became globally integrated. The industrious revolutions were based on a co-evolution of labor and knowledge about how the goals of production could be achieved in an economically more effective manner. These revolutions became the prerequisite for the emergence of new economic systems, forms of religious organization and of science as social systems in their own right. Thus, while science may have been temporarily closely associated with industrialization, it emerged on a global scale as a social system that carries no specifically European traits. In contrast to Gunder Frank, who argues that the emergence of science, the development of technology and industrialization should not be conceived as interdependent processes, Bayly advocates a radical application of the globalization paradigm. According to this paradigm, any development is mediated by a worldwide interplay of processes, thus constituting globalization in the first place. He thus opposes previous historiographies which considered developments as rather taking place in a chronological sequence.

Frank, on the other hand, emphasizes the autonomy of economic, political and scientific developments in Asia which remained unnoticed for centuries by Europeans. He also denies that the rapid development of capitalism and the industrialization in Europe represented singular historical events. He rather claims that the Chinese form of economy was equally successful. In his view, the global economic system emerged over centuries as the result of an interplay between different regional economic systems. With regard to the European development, he stresses that "any such Western rise must have been *within* the world economy itself" (Frank 1998, 334). Effectively, he turns the view of an alleged European singularity and superiority upside down by claiming that one has to interpret the entire complex of capitalism, industrialization and technical progress in Europe as ultimately resulting from Europe's success in learning to stand on the shoulders of the Asian economies.

With a focus on Great Britain, Jürgen Osterhammel introduces a periodization for global history. He regards the decades between 1770 and 1830 as a "global saddle period," marked by the Industrial Revolution. It comprises the development of wage labor from 1820 on, the deployment of fossil fuels and the massive spread of steam engines (Osterhammel 2009, 108). This global saddle period is followed by the "Victorian globalization" lasting until 1890. It is characterized by imperialism, the emancipation of white settler societies in North and South America, nationalism, the importance of civil liberties and the rise of the middle class. With regard to the global character of the contemporary intellectual history, Osterhammel takes a cautious stance because, as he writes, too little is known about the individual "contacts and relations of exchange between the individual civilizations [...] from non-occidental contexts" (ibid. 108-109).

Osterhammel distinguishes between industrialization and the Industrial Revolution, two terms often used synonymously in historiography. For him, industrialization is characterized by slow growth; it is not necessarily coupled to capitalism or accompanied by a major impact on society. The Industrial Revolution, on the other hand, distinguishes itself by its far-reaching effects on society and its global impact. The prerequisites for the emergence of the Industrial Revolution existed only in Great Britain. Among the conditions favoring the Industrial Revolution were a large demand for bulk goods, a well-developed international trade and an elaborated scientific tradition and great technological experience.

The British economic context in fact also favored a second scientific revolution in which, in contrast to earlier epochs of history, "the waves of innovation did not break off or peter out" (ibid. 918). Osterhammel describes the cumulative character of this process of innovation, which he considers to be a unique characteristic of Great Britain, by referring to a "*normalization* of technical innovations." In his view, it results from a particular interplay of already existing and systematically produced new knowledge. The development of new technologies for converting energy, for instance, was furthered and accompanied by the capability of formulating physical models of such conversion processes. For Osterhammel, the nineteenth century was, in fact, a period in which social and scientific progress were both closely linked with each other, as well as with the issue of energy conversion, in particular from fossil fuels (ibid. 928–930).

Also Walter Mignolo sees close parallels in the development of politics, capitalist economy and epistemology when he traces the expansion of Spain during the sixteenth century. He claims, in particular, that this historical development shaped modern philosophy and, more generally, modern thinking with effects lasting until today. The starting point of this development was the global challenge with which the Spanish monarchy was confronted as a consequence of the expansion of Iberian powers to America and other parts of the world. Through this expansion, Spain assumed a central position and became a mediator largely determining the epistemological framework for interpreting the new, global world (Mignolo 2000, 56).

As a response to this challenge, epistemic strategies were developed to integrate the new experiences into the existing complexes of politics, faith and power. Thus, under the auspices of Spain's Catholic monarchy, a self-contained epistemological system was established that excluded any claims to scientific validity coming from the outside and that continued to bend and twist anything not in accordance with it (ibid. 4–5). This system which Mignolo designates as "occidentalism" indeed remained in power long after the demise of the period properly labeled as colonialism (ibid. 53). In particular, this system entered into a close, functional relationship with the expanding capitalistic world system. Following Aníbal Quijano, Mignolo sees close parallels between the relation of owner and property in capitalism and the epistemic subject-object relation (ibid. 60), and more generally between the development of global capitalism and that of knowledge systems.

Also Serge Gruzinski is convinced that the globalization of knowledge was deeply shaped by capitalism. But he widens the economic perspective to include the circulation of luxury goods, in particular, in the sixteenth century. Luxury goods, marvels and curiosities traded in Europe since the Middle Ages were recognized on all continents as gifts and became objects of global consciousness and worldwide trade (Gruzinski 2004, 43–47). For Gruzinski, genuine globalization means assimilation, a central topic of his studies. The traded "exotic" luxury goods were assimilated by economic processes and incorporated into a social value system from which a new form of economy emerged. Through these assimilation processes, new stocks of knowledge were built up that could have hardly emerged in the world prior to Iberian expansion, with its mostly autonomous knowledge traditions.

> The connection between one or the other world is not limited to the translation of indigenous issues into an Iberian language and to European codes. However, the connectivity would be imperfect without the further inclusion of an indigenization or an Africanization of European issues. (ibid. 242–243)

Peter Stearns broadens the discussion about capitalism and Industrial Revolution by emphasizing the importance of transport and communication for the history of globalization in a long-term perspective. Accordingly, he takes a close look at the spaces of communication and trade before 1500. According to Stearns, wide ranging connections emerged as early as the Bronze Age. During this period, the transfer of knowledge occurred on the basis of certain goods that had become objects of desire in places other than their regions of origin. This interest in objects, but also in production methods such as metal smelting techniques, stimulated a search for knowledge and learning that also motivated mobility. In antiquity, for instance, scholars visited other cities and countries because they were interested in their local knowledge. Greeks went to Egypt and Chinese scholars visited India. Some were seeking mathematical knowledge, others were interested in religious matters. In any case, knowledge became something like a material good. Through this mobility of scholars, as well as by way of the exchange of manuscripts, contacts emerged, many of which proved enduring (Stearns 2010, 9–10).

For the period after antiquity, Stearns closely follows the development of trade and language as vehicles of a "proto-globalization." He emphasizes the importance of relationship-building in the expanded Mediterranean area and attributes a significant role to the Arabs and their culture of trade. For Stearns, trading is in fact the true motor of the Arab expansion that transported not only goods but also their language. Thus Arabic became the lingua franca of the Mediterranean and of the Indian Ocean. In the Arab world, a wide-ranging network of intellectual centers emerged with close relationships between each other. Scholars were able to travel back and forth, exchanging religious or legal knowledge, because travel was considered to be safe (ibid. 32–36).

For the Middle Ages, Stearns shows that the diffusion of knowledge was closely linked to that of the objects to which the knowledge referred. He discusses, in particular, the examples of silk and porcelain. Although the knowledge of their production was protected by political entities, it was nevertheless distributed ever further through trade (ibid. 36). The period between ca. 1500 and the Industrial Revolution saw important developments of transportation technologies, leading to an increase of both loading capacity and speed. The invention of the printing press with movable type in Europe became a key element of increased and accelerated communication, although this was not the purpose of its invention (ibid. 63).

While other scholars would characterize these developments as the beginning of globalization, Stearns places its true inception around 1850. He agrees that the fundamental elements emerged around 1500 and were improved in the subsequent period (ibid. 87–93). But he stresses that, during the long nineteenth century, the speed of transport and communication significantly increased, as did the capacity to transport bulk quantities over large distances (ibid. 93). He sees trade and war as the most important motors for the further development of the corresponding technologies. However, the accelerated globalization was not limited to developing means of ever faster and more efficient transport, or to the greater speed at which innovation took place. For Stearns, the key to the true inception of globalization was the quicker diffusion of these innovations which now occurred within a few decades or even within just a few years (ibid. 106). He summarizes:

> Technology breakthroughs in transportation and communication alike, new approaches to global health issues and the massive acceleration of technology diffusion, really new areas of global interaction in culture and politics, and crucial commitments from key nations like Japan—the list of fundamental innovations is substantial, and might easily justify the idea that the post-1850 period is indeed the crucible of modern globalization. (ibid. 122)

Stearns is of course aware of the problems associated with a strict periodization in globalization history. Regional differences, differences between urban and rural zones or the various forms of interaction between the local and the global in fact challenge any specific temporal framework (ibid. 125–127, 150).

William and John McNeill also deal with global history in a long-term perspective. They focus on Europe and the special position it achieved in the long development from antiquity via the Scientific to the Industrial Revolution. Their story begins with the routes that had connected distant regions such as Mesopotamia and China as early as the first century BCE (McNeill and McNeill 2003, 65). They stress the particularities of ancient Greece and its pluricentric political and religious organizations, as well as the role of Aristotelianism for the further development of knowledge (ibid. 73–74). Steady cultural contacts stimulated the transfer of knowledge and fostered the development of technologies in areas such as navigation, war, astronomy and physics (ibid. 189). The authors thus identify an "Old World Web" of far-reaching connections, but also refer to epidemics as a complementary unifying force since they entailed significant consequences for political communities all over the world (ibid. 78–79).

The Arab expansion was accompanied by the spread and accumulation of knowledge which was eventually institutionalized in madrasas. Sciences in the Arab world flourished until well into the fifteenth century and beyond. Important contributions to mathematics, astronomy and medicine were achieved in this period, some of them with challenging consequences for religious knowledge. The authors nevertheless locate the Scientific Revolution in Europe, between the sixteenth and eighteenth centuries. Here, against the background of a political fragmentation that encouraged competition, modern science emerged as a system supported by the institutional framework of universities and was based on a well-established tradition of flows of information and fields of scholarship (ibid. 186–188). This European Scientific Revolution created important conditions for the further development of a globally connected humanity.

Even more than the Scientific Revolution, according to the authors, it was the Industrial Revolution that changed human history. The use of fossil fuels turned out to be essential for the development of worldwide connections and the formation of the modern world. The Industrial Revolution had its origins in England where a number of favorable conditions prevailed, such as the introduction of new technologies, but also the utilization of previously unexploited land and an advantageous political situation. The authors trace the unfolding of the Industrial Revolution through various stages. At first, innovations were mainly introduced by practitioners and entrepreneurs. Only in the final stages did science play a fundamental role in the development of new technologies. Eventually, the Industrial Revolution also had far-reaching consequences on local industrial sectors outside of Europe. The cotton industries in India, Bangladesh and Iran, for example, were unable to compete with the British industry. In these parts of the world, modes of industrial production were only developed after European machinery was imported (ibid. 230–237).

In conclusion, as John and William McNeill consider a long time span of human history, they keep sight of the connectedness of different parts of the world, a connectedness that persisted for centuries and that can be considered as being the quintessence of globalization. Because of its fundamental implications for all parts of the world, however, the Industrial Revolution emerges as the single most important historical process shaping this globalization.

2.6 Summary

While all of the authors considered here are evidently aware of the important role of knowledge and science in the history of globalization, only for Walter Mignolo and Serge Gruzinski do they form an essential part of their narratives. As we have seen, for Mignolo epistemology plays a decisive role while Gruzinski emphasizes the exchange of knowledge. For the other authors, economic developments and political histories form the backbone of their reconstructions.

Authors with entirely different outlooks nevertheless agree on the fact that certain key periods existed that fundamentally changed the further history of the world. In Osterhammel's *Verwandlung der Welt*, this period is around 1850, while in Gruzinski's *Les quatre parties du monde* the period around 1600 marks a crossroads in history.

All of the authors agree not only on the importance of knowledge and science, but also on the role of global connections in constituting globalization. They conceptualize these connections, however, in somewhat different terms. For Christopher Bayly, they are embodied in spaces of intensive debates, such as those on liberalism, socialism, science and the late colonial situation; for John and William McNeill they are part of an ever-growing network; for Mignolo they take the form of different epistemic systems that were formed during colonialism; for Gruzinski, the essential process consists in the mixing of cultures and people; and for Peter N. Stearns, these connections intensify over centuries and are built up by forms of communication and mutual observation, as well as by the exchange of knowledge between systems, institutions and actors.

As we have seen, the question of Europe's uniqueness is studied intensively in all of these works. The most prominent theme that connects Europe with another continent consists in the exchange between Europe and Asia, especially China. Bayly and Frank stress the mutual interaction between both continents, while the one-way nature of knowledge transfer from Europe to Asia prevails in Osterhammel's account. In practically all of the studies considered, Europe is seen as a special place characterized by diversity, where a persisting competitive situation became the motor for the development of knowledge, science and technical innovation. This competitive situation was due to the permanent confrontation between political units, but also to the rivalry and constant exchange between institutions of learning, such as the universities, as is emphasized by Osterhammel.

According to Mignolo, a North-South divide of Europe was the cause of an epistemological decline in the Mediterranean countries, with industrialization affecting only a few of the Middle and Northern European regions, as Bayly, Osterhammel and Stearns all point out. At the same time, Osterhammel and Gruzinski emphasize in their works how Europe resisted the influence of non-European knowledge, partly because it was, for most Europeans, difficult to assimilate to their own systems of knowledge. In the seventeenth century, Europe lived in an Aristotelian bubble and, in the nineteenth century, in imperialistic arrogance.

Most studies identify trade, economy and production processes, but also religion, language and politics as important vehicles of knowledge. They also notice how systems of knowledge, carried by these vehicles, are developing into sub-structures of the expanding world system. They furthermore suggest to conceive such systems of knowledge in terms of models, world orders and narrative metaphors taken from political and economic history. Finally, the studies follow the historical changes and developments of these systems of knowledge, alongside those of the objects of knowledge. Some, such as Bayly's and McNeill's accounts, propose stage models of knowledge development, favoring scientific knowledge as a superior form of knowledge, while others, such as Serge Gruzinski's account, consider catalogs and collections, for instance, as an autonomous form of science and not simply as precursors to its developed Western form.

The relation between knowledge and science constitutes, more generally speaking, a challenging problem for globalization studies that is not always confronted in an explicit manner. The way this problem is dealt with depends, of course, also on the temporal focus of a historical study, given the obvious differences between pre-modern and modern types of knowledge organization. It is also related to the controversial questions of when globalization began and what role Europe played in it. While Europe's role remains crucial, all authors make considerable efforts to pay attention to other continents. Clearly, what is still missing are, as Osterhammel remarks, studies of exchange processes between non-European historical entities, for instance, between Asia and Africa. Addressing the question of the relation between knowledge and science is often circumvented by considering institutions as the real objects of investigation or by applying a modern notion of science to earlier periods.

Another challenging problem emerging from the available accounts is the historical understanding of the relation between the Scientific Revolution and the Industrial Revolution, as well as of the relation between capitalism and industrialization. What role did knowledge and science play in these processes and their interconnections? And vice versa, how should we conceptualize knowledge and science in order to arrive at a better historical understanding of these developments? Further research on these questions will help not only to achieve a more symmetrical global history of knowledge, without glossing over differences of power, or over the confrontations and wars that are also part of the global history of knowledge. It will also help to address some of the issues with which current globalization confronts us.

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PART 1: From Technology Transfer to the Origins of Science

Chapter 3
Survey: From Technology Transfer to the Origins of Science

Malcolm D. Hyman and Jürgen Renn

3.1 The Beginnings of the Globalization of Knowledge

By definition, globalization processes in the contemporary era have involved geographically disparate peoples and the spread of ideas, knowledge and technologies by a variety of means over vast distances. If we pose the question as to when such processes first began, then it must be acknowledged that long-distance, indeed intercontinental, connections with an attendant spread of knowledge are as old as Homo sapiens itself. It is true, connections and contacts between distant parts of the world remained accidental and sporadic for most of human history. Only in the last century or two have such contacts taken the form of a continuous, systematic and self-reinforcing global exchange of knowledge that is turning more and more into a condition for human survival, thus launching us into a socioepistemic evolution in which change in human society is driven by the generation of knowledge.[1]

But some of the basic mechanisms of the global exchange of knowledge and its interdependence with other processes of transfer and transformation may well be recognized even in the earliest phases of human development. All of these processes are layered, in the sense that the introduction of a new process does not lead to the eclipse of earlier processes. Consequently, the globalization of knowledge is a deeply historical process in which the dynamics at any given stage depends not only on the outcome of the preceding one, but on the entire developmental trajectory back to some of its initial biological and ecological conditions. To understand the globalization of knowledge today and its role as a backbone of a future socioepistemic evolution, we therefore have to revisit this developmental trajectory from its inception. There is another, more proximate reason to do so: ignoring the role of knowledge in the development of human societies necessarily leads to inadequate descriptions; thus, for instance, the study of long-range transfer in prehistorical archaeology has been hindered by a lack of focus on knowledge.[2]

A number of global characteristics of human life developed in prehistoric times, among them the use of language, the ability to produce tools and weapons, especially artifacts made of wood and stone, metallurgic knowledge and—after

[1] For a more detailed discussion, see chapter 24.
[2] See, for example, (Renfrew and Zubrow 1994; Renfrew 2009).

the change from hunting and gathering to sedentariness—the knowledge to construct dwellings, to manage agricultural cycles of planting, harvesting and storage of cultivated plants and fruits, as well as the technologies of livestock breeding and diverse uses of domesticated animals.[3] Later came the use of symbolic means such as iconography, measurement, writing and arithmetic, eventually followed by the development of early forms of scientific knowledge. The global or potentially global character of these bodies of knowledge may result from two different kinds of historical processes and their interaction over time. Different but functionally equivalent bodies of local knowledge may merge into an integrated knowledge system as a result of cultural exchange processes. Alternatively, a useful body of local knowledge may be disseminated to or be adopted from neighboring cultures, thus spreading until it becomes a global human characteristic.

3.2 The Spread of Knowledge in the Context of the Migration of Early Humans

There is considerable evidence that humans and their close hominid kin moved out of Africa in several waves over half a million years. The earliest fossil evidence of anatomically modern humans at Omo I in Ethiopia is thought to be ca. 190–200,000 years old,[4] while the earliest evidence from the Near East (Qafzeh and Skhul Cave, Israel) is ca. 90–100,000,[5] and from Europe not more than ca. 30–25,000 years.[6] The *out of Africa* hypothesis of early modern human dispersal (probably just one of a number of waves of migration out of Africa that had been going on for over half a million years)[7] appears to be basically correct, at least with respect to Europe and Western Asia.[8] Nonetheless, the possibility that archaic Homo sapiens in East Asia evolved directly out of the local Homo erectus population cannot be ruled out completely (regional continuity model). Yet this scenario, too, would have entailed a good deal of interregional migration as areas like Australia (Adcock et al. 2001) and Siberia (Vasil'ev et al. 2002) were progressively colonized from at least 60,000 years ago. Numerous knowledge systems and technological realms as well as knowledge transfer of intercontinental, pan-Eurasian proportions can be readily documented in the pre-modern era. Even before the ascendency of modern humans, the spread of early hominids was concomitant with a spread of knowledge related to stone tool technology that led to the creation of a wide range of Upper Paleolithic tool traditions.

[3]The following survey of prehistoric developments includes a draft provided by Dan Potts, see also chapter 4.
[4]See (McDougall et al. 2005, 2008).
[5]See (Schwarcz et al. 1988; Andrews and Stringer 1989; Grün et al. 2005).
[6]See (Pereira et al. 2005; Soficaru et al. 2006, 2007).
[7]See (Templeton 2002).
[8]See (Larick and Ciochon 1996; Quintana-Murci et al. 1999).

3.3 The Spread of Agriculture and Other Early Cultural Techniques

Knowledge spread also with the later expansion of agricultural technologies relating to the domestication of cereals and animals. Intensive gathering of wheat and barley in the Fertile Crescent led eventually to agricultural practices that resulted in the genetic modification of cereals (domestication) about 10,000 years ago. Evidence for the domestication of small cattle (sheep, goats, pigs) dates this practice to ca. 8000 years ago. Within one or two millennia these agricultural advances together with the domesticated cultivars spread, through demic migration, to southeastern Europe and thence northward through Europe and eastward to Central Asia. At approximately the same time (ca. 9000 years ago) rice cultivation in north and south China gradually began to spread westward through the Indus Valley (ca. 5000–4000 years ago) to the Persian Gulf and Mesopotamia (ca. 3000 years ago).[9] Cultivars such as these were certainly never "disembodied" from the knowledge systems required for their successful cultivation (except much later when exported in bulk as commodities). Instead it was a gradual demic diffusion that brought cultures into contact, thereby introducing them to the technologies and practical knowledge of other cultures. Agricultural practices required a detailed body of practical knowledge concerning strategies for sowing, tillage, tending, harvesting and processing. With the adoption of these practices we see the shift from a hunter-gatherer to a sedentary mode of existence; with the emergence of sedentary cultures, new possibilities for the accumulation and spread of knowledge opened up.

Ceramic technology, for instance, first attested around 8500 years ago at Ganj Dareh in Iranian Luristan, may have spread westwards into Europe as part of the Neolithization process.[10] It is attested even much earlier in Eastern Asia. Ceramics have been found at early Neolithic sites in southern China (e.g., in Mioyan, Yuchanyan, Xianrendong and Diaotonghuan) in contexts dating as early as 16,000 years ago, while the earliest pottery in Japan, belonging to the Jomon culture, appeared ca. 13,000 years ago.[11] In the realm of music, specific instruments spread widely across Eurasia. The arched harp, for example, is attested iconographically at Choga Mish in southwestern Iran ca. 5400 years ago. A sign representing an arched harp appears in the Harappan or Indus Valley script over 4000 years ago and the instrument is attested in Vedic and later Buddhist sources, in Burmese art and texts, at Penjikent in Sogdiana, on the Silk Road, around 1200 years ago, and at Dunhuang in western China during the Song Dynasty (960–1279).[12] All

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[9] See (Liu et al. 2007).
[10] See (Hole 1987).
[11] See (Kharakwal et al. 2004).
[12] See (Lawergren 1994).

in all, for many issues that were still controversial several years ago, the diffusion argument seems to have won the day.[13]

3.4 The Spread of Animal Husbandry and Implications for Long-Distance Transport

The diffusion of knowledge across the Eurasian landmass, however, was not confined to the gradual, overland expansion of small groups of people moving into new areas and the ensuing exposure of other groups to their technologies. The domestication of equids (*Equus asinus* and *Equus caballus*) and camelids (*Camelus bactrianus* and *Camelus dromedarius*) increased the possibility for disparate groups to communicate with each other over great distances. These transport animals, later also used for riding, constituted a new, faster means for the spread of not only goods but also knowledge. In an earlier period, precious goods such as obsidian, lapis lazuli, marine shells, ivory, copper, tin, silver, gold and electrum could be traded through a series of relays from community to community or region to region. Once transport animals became available, trade was greatly facilitated and more complex large-scale economic structures developed. The domesticated Bactrian camel (evidenced in Inner Mongolia ca. 8100 years ago) facilitated long-range Eurasian contacts three millennia or more before the historically attested Silk Road caravan trade. The Bactrian camel had spread massively westward across the central Eurasian steppes, beginning ca. 6000 years ago, reaching Syria a thousand years later, demonstrating a dramatic increase in human mobility within regions of Eurasia (Potts 2004). Arabian camel caravans were impossible until the much later domestication of the dromedary after ca. 1000 BCE (Uerpmann and Uerpmann 2002). These developments made targeted trading expeditions and military forays possible, and moreover made accessible regions hitherto inaccessible; as a result, corridor-like connections emerged, spanning an extended geographical network. Thus in this period, geographic knowledge must have increased and spread dramatically.[14]

New possibilities for maritime travel also emerged in the mid-Holocene. Evidence points to the existence of early watercraft in the Persian Gulf ca. 8000 years ago. Nor was coastal sailing the only option for early mariners. The discovery of banana phytoliths in the interior of Africa at the site of Munsa (Uganda) in contexts some 5000–6000 years old—together with the absence of banana at any intervening sites in Southeast Asia, India or the Arabian peninsula—strongly suggests that the banana was transported by sea from its origin in Papua New Guinea (Lejju et al. 2006). Until recently, most scholars did not believe the banana had been introduced into Africa until the first millennium CE. Intensive

[13] See chapter 4, in particular, section 4.2. Potts emphasizes that an examination of the spread of the technologies underlying the production of certain artifacts offers an alternative to the study of the spread of the end products themselves.

[14] For further discussion of such corridor-like connections, see the survey of Part 3, chapter 9.

banana cultivation in New Guinea is now known to have begun ca. 6500 to 7000 years ago (Denham et al. 2003). Thus trans-Indian Ocean sailing was a reality at least 6000 years ago. Some 1500 years later, long-distance sailing between India, southeastern Arabia and Mesopotamia was becoming routine.[15]

By the end of the fourth millennium, Eurasia was well connected by trade routes running along east-west and north-south axes. These routes allowed for economic, technological and epistemic interchange. In contrast, in the Americas similar processes took place, such as the domestication of plants and animals, sedentariness, the development of technology such as ceramics and metallurgy and ultimately even urbanism and writing, but the extent to which these developments were exchanged was limited. Greater geographical obstacles constituted fundamental limits, impeding long trade routes. The climatic diversity resulting from the north-south axis of the continents limited zones of population contact as well as the transfer of agricultural achievements.[16]

3.5 The Spread of the Proto-Indo-European Language as an Example of Knowledge Disseminated Through Language

Knowledge also spread with language, as language spreads with migration, conquest and trade. Before 3000 BCE, speakers of a Proto-Indo-European language began to spread throughout Eurasia.[17] By the fifth century CE, we have firm evidence that descendants of this language ranged from Ireland in the West to the Xinjiang province of China in the East. The Proto-Indo-European language was transmitted in part by demic migrations, but also through being adopted, apparently as a prestige language, by indigenous alloglottic populations. With the language were transmitted the social structures, religion, legal institutions, literary tradition, and medical and architectural knowledge of Proto-Indo-European society. This knowledge and these institutions were transmitted in large part by a technology of oral poetic composition that built upon and extended the potentials inherent in spoken language; this is probably the first mnemonic technology and almost certainly predates writing.[18] Formulaic verbal expressions (e.g., legal formulae) were a crucial vehicle for the transmission of the symbolic and technological knowledge of Proto-Indo-European culture; these could be embedded in traditional oral poetry (as exemplified by the Homeric epics). Such formulaic expressions can be reconstructed from literature of the descendant languages of Indo-European, such as Hittite, Vedic Sanskrit, Ancient Greek and Latin.

Linguistic reconstructions attest a culture characterized by an aristocratic class concerned with religious and military affairs; an organic conception of com-

[15] See (Cleuziou and Tosi 1994; Potts 1995), see also (Meyer et al. 1991) for evidence of long-distance sailing between the environs of Zanzibar to Tell Asmar in northeastern Iraq. For an overview of "the maritime Silk Road," see (Ptak 2007).
[16] See (Diamond 1998).
[17] See (Cardona et al. 1970; Haudry 1981; Mallory and Adams 2006).
[18] See (Rubin 1995; Watkins 1995).

munity in which the structures of the whole society mirrored those of the individual family; a public law based on contract; the practice of divination; and a tripartition of medicine into surgery, pharmacotherapy and healing by spells or incantations.[19] Religion played a key role in the transmission of knowledge, and it has been argued that with rituals (and associated verbal recitations), specific geometrical and architectural knowledge—needed to construct ritual altars—traveled from Central Asia to India and Greece.[20] It is, however, still debated whether Indo-European language and culture spread by means of agricultural diffusion, or by military expansion with a mostly nomadic form of economy. As a matter of fact, military expansion is also often accompanied by the diffusion of technologies, military and others and slave trade, as well as enslavement, in the wake of wars may serve the diffusion of crafts and expertise.

3.6 Urbanization in Babylonia and the Invention of Writing

In the fourth millennium, we see the beginning of large-scale settlements in Babylonia. At this time we also see, not coincidentally, the development of writing, which in time will lead to a dramatic increase in the durability and transportability of knowledge.[21] The urbanization processes centered in Uruk and Susa, which reached their acme in the middle of the fourth millennium, led to the development of new cultural products, such as architecture, cylinder seals (as opposed to stamp seals), the mass production of pottery, as well as proto-writing and proto-arithmetic.[22] The precondition of both the seals and of writing is the human capability to represent experiences symbolically, a faculty that developed at least 30,000 years ago. Writing appeared around 3300 BCE in Mesopotamia; the largest group of texts is from Uruk, but other text groups have been found in northern Babylonia. A group of texts found in an Egyptian grave in 1989 may be contemporaneous with the beginning of writing in Mesopotamia, but most likely these texts are somewhat later.[23] The earliest documents are clay tablets with numerical notations and sealings that likely indicated institutional contexts. By ca. 3300 BCE, a system known as archaic cuneiform or proto-cuneiform had developed. The vast majority of proto-cuneiform tablets were instruments for representing practices of accounting and administration associated with the new urban culture. This early writing was hardly, and possibly not at all, related to the structure of spoken language. It thus did not represent the meaning of words or sentences,

[19] See (Benveniste 1945, 1969).
[20] See (Staal 1999).
[21] See (Nissen et al. 1993; Englund 1998; Woods 2010). See also chapters 5 and 6. The following is based in part on comments by Jens Braarvig.
[22] According to Damerow, local developments of writing and arithmetic have interacted in various ways over the course of history. In the case of arithmetic, the end result was a unified system of arithmetical notation and calculational methods. In the case of writing, historical globalization processes have spread writing all over the world, but have neither led to a unification of languages nor of writing systems (see chapter 6, section 6.1).
[23] For an overview, see (Stauder 2010).

nor did it reflect grammatical structures of language, but rather meanings related to specific mental models of societal practices such as accounting. It was on this basis, however, that the second invention of writing, that of writing as a universal means of codifying language, eventually took place.

Traditional studies have presented writing as a technology, the purpose of which was to record spoken utterances with fidelity. This began with pictograms and inevitably moved toward full alphabetic writing.[24] Recent literacy studies, associated above all with Jack Goody and Ian Watt (1963; 1986), conceived of writing, in the words of Walter J. Ong (1986), as a technology that restructures thought. In both lines of research we see emphasized, on the one hand, the form of writing, and on the other, the consequences of writing. Both downplay the diverse purposes of writing, the varying social needs that writing addressed in ancient cultures and the emic perspective of how practitioners (professional scribes, lay readers and so forth) themselves conceptualized writing.[25]

Writing arose in Mesopotamia, as we have emphasized, and for some time it remained closely tied to practices of politico-economic administration. In Egypt, writing was more closely tied to the display of monumental inscriptions which served to legitimate the authority of priests and rulers. Here, the aesthetic aspect of inscription was foregrounded and writing was closely linked to artistic and architectural purposes. From these beginnings, writing began to be put to more and more uses: epistolography, historiography, the recording of empirical observations, *belles lettres*. With changes in function, adaptation to new societies with varying socioeconomic structures, and adoption by different classes, writing took on new forms, as in the transformation of hieroglyphic into hieratic and demotic, the evolution of a predominantly logographic Sumerian cuneiform into a predominantly syllabic Akkadian cuneiform, and in the development of the West Semitic writing systems.

From the perspective of writing as an external representation of knowledge, it is necessary to compare the various ways in which writing encodes knowledge. The earliest writing was primarily, if not exclusively, non-glottographic, that is, its structure was not derived from that of spoken language (Hyman 2006). Later, we find writing exhibiting a closer dependence on spoken language, but apparently still sometimes encoding event structure more or less directly, rather than linguistic structure. Thus we often find indications of actor, action and object, while grammatical morphemes are absent or underrepresented, and modality, for instance, lacks any exponentiation whatsoever.

Writing also plays a key role in the standardization or canonization of knowledge: in standardizing systems of classification (e.g., Sumerian lexical lists), legal codes (e.g., Hammurabi's Code, Deuteronomy, the XII Tables), calculation techniques (e.g., mathematical tablets), and literary texts (e.g., the vulgate of the Homeric epics). Likewise writing, in fixing certain knowledge (e.g., astronomical

[24]See, for example, the work of Ignace J. Gelb (1952, 1963).
[25]For more recent studies, see (Halverson 1992) and (Collins and Blot 2003, in particular, 9–33).

diaries), allows reflection on that knowledge and the generation of more abstract theories or models (such as arose in Babylonian or Greek science).[26]

Concomitant with the invention and use of writing, a number of fields of knowledge were accordingly facilitated and developed during the third millennium BCE to serve the state—the developing bureaucracy of administration, military activities—and trade and religion, viz. accounting and lists of resources, metrology, mathematics, medicine, formalized law, lexicography, historiography and poetic literature both inside and outside of the religious sphere, not to mention the tremendous activities concerned with "scientific" divination.[27] With the advent of writing, trade and the exchange of goods on a larger scale were also developed, accompanied by written contracts, agreements and systematic and regulated forms of communication, also developing into multilingual formats.

3.7 Multilingualism, Language Contact and the Spread of Knowledge

The ancient Near East is not only the site of the earliest known writing, it is also the first location for which we possess evidence of a multilingual culture. From the beginnings of Sumerian literature, there is already evidence (lexical and onomastic) for a diverse multilingual society in which there were not only speakers of Sumerian, but also of languages belonging to the Semitic family. Incantation texts in both Sumerian and Semitic versions existed as early as the Fara period (ca. 2500 BCE) and suggest a culture in which Sumerian was a "foreign" language for many scribes. Starting in the seventeenth and eighteenth centuries, we find Old Babylonian Grammatical Texts in the form of Sumero-Akkadian and Akkado-Sumerian glossaries. These texts not only bear witness to a culture that explicitly recognizes its own multilingualism, but also constitute the first historical moment at which humans began to engage in a significant reflection on their own language(s)—at this moment metalinguistic knowledge was born. That Sumerian already existed in a bilingual culture as early as the Fara period is also suggested by the fact that many of the scribes appearing in the colophons in the Abu Salabikh texts from the Fara period had Semitic names, even though otherwise the texts themselves never include Semitic linguistic forms.[28]

Ancient multilingualism is further attested by the culture of scribes working with several languages. Additional evidence is found in the frequency of translation, for example, from Akkadian to Hittite and Hurrian, from Hurrian to Hittite. We find, for example, the Gilgamesh Epic in a number of translations. Akkadian was used as a diplomatic language and lingua franca for the Hittites and Ugarit royals to communicate with their Egyptian counterparts. This amply demonstrates

[26] See chapters 6, 7 and 8.

[27] See chapter 7. A standard reference is (Neugebauer 1957). For the historical context of the emergence of mathematics, see (Robson 2008; Damerow 2010).

[28] See (Biggs 1966; Biggs and Postgate 1975; Cagni 1981; Krebernik 1984, 2007). For a general overview, including all relevant literature, see (Krebernik 2007).

how states chose to communicate with each other in a third standard language as early as the second millennium BCE. The Persian Empire, and later also the Aśokan Empire in India, used multilingual media to communicate their decrees and ideas to their multilingual empires, remains of which we find in the Behistun inscription and the famous inscriptions of Aśoka in Maghadi, Aramaic and Greek, where Aśoka promulgates religious tolerance to both his own empire and to his neighbors. As recent research in anthropology, linguistics and psychology has amply demonstrated, multilingualism is the norm in human culture. The history of civilization is largely a history of peoples who, to varying degrees, have negotiated a multilingual environment, created by factors such as population movements and expansions, exogamy and economic insufficiency.

3.8 The Spread of Babylonian Culture

The knowledge connected with Babylonian cultural products, including writing, spread over large areas of the Near East, from the Levant to Iran. It is not always clear to what extent such techniques were adopted by local cultures with long-term effects, or whether they remained merely a superficial contact phenomenon.[29] Following the Uruk period (3400–3000 BCE), a fragmentation of societies can be observed, a phenomenon that can be attributed to ecological and demographic changes. Common cultural traits, however, such as the technique of writing, were preserved and even further developed.[30]

Around the middle of the third millennium we see a major interregional contact sphere that must have promoted considerable cultural exchange in the interconnected societies. Even before the emergence of the first contemporaneous empires, during the period of feuding "city states," cultural technologies such as writing had already spread from southern Babylonia to the Levant (i.e., Ebla). Writing had also undergone significant changes in the meantime and was now phonetically representing the structure of spoken language (Krebernik 2007). As early as 2500 BCE, we find written collections of proverbial sayings (Alster 2005, in particular, 31–220). Long-term record keeping is also attested for the first time. The Old Akkadian centralized state (ca. 2350–2200 BCE), incorporating various traits of its predecessors, attests to the emergence of newly ordered institutions (kingship, standing armies, palace administration) and significant processes of standardization in writing, metrology and other areas. During the subsequent Ur III period (ca. 2100–2000 BCE), known for its enormous administration, we find the first traces of new forms of written literature and historiography, which built

[29] Cancik-Kirschbaum emphasizes the need for a host of techniques to access the knowledge stored in writing (chapter 5, section 5.1). She argues that writing should not be conceived as automatically fostering the globalization of knowledge, since it requires a high degree of specialization and practices that are localized both in space and time (section 5.4).
[30] For the Uruk period, see (Englund 1998).

to a large extent on older traditions and established a framework for the cultural identities of ensuing societies.[31]

The organization of society underwent tremendous changes in the following periods. In addition to the temples, we find a largely independent state administration, as well as a tendency toward increased individualization and privatization, including the possibility of private property and individual economic ventures. As far back as the Old Assyrian (ca. 1950–1750 BCE) and Old Babylonian (ca. 1850–1600 BCE) periods, we already observe a reduced number of cuneiform signs in use, which facilitated everyday communication, attested in letters and administrative documents. This process, which can be thought of as a "democratization of writing," is paralleled by the slightly later invention of alphabetic scripts in the Levant.[32]

New forms of written knowledge that appear in this period include: grammatical texts; divination texts; lists, which will eventually evolve into specialized genres such as star-lists; historiographical texts, such as copies of Old Akkadian royal inscriptions; the first Akkadian literary corpus; private legal documents; "mathematical" texts; healing texts; astronomical texts; and so on. In this period, we also find a number of multilingual lexical lists, documenting the written and formalized multilingualism in the area, which throughout history is characterized by great language diversity. Some of these texts had precursors, but the level of systematization attempted, and in part achieved, during this period sets them clearly apart from earlier texts. A major part of this literature was transmitted and preserved in schools linked to the temple rather than to the palace administration (which represented the actual seat of power during this period). For the first time we can observe a clear knowledge dichotomy between state institutions and religious institutions. This opposition became crucial in the creation and transmission of knowledge for the remainder of Mesopotamian history and persists to the present day.[33]

The canonization of Babylonian literature took place to a large extent during the Kassite Dynasty (ca. 1600–1300 BCE) (Lambert 1957). We can interpret this process as a conscious attempt to incorporate existing patterns of knowledge. This knowledge spread far beyond the borders of Mesopotamia to Anatolia, Iran and even to some extent to Egypt, influencing local knowledge traditions. As Mesopotamia became an international power from the twelfth century BCE onwards, the collecting of knowledge was increased and became a thoroughly systematic enterprise. The attempt to organize knowledge systematically led to the accumulation of vast amounts of knowledge, particularly in the areas of astronomy

[31]For the early dynastic period, see (Bauer 1998; Krebernik 1998) and for the Ur III period (Sallaberger 1999).

[32]For the Old Assyrian and Old Babylonian periods, see (Charpin et al. 2004; Veenhof and Eidem 2008).

[33]For the Old Akkadian period, see (Westenholz 1999). Further discussion can be found in the survey of Part 2 (chapter 9).

and meteorology.[34] In this period, Akkadian was a lingua franca and a powerful instrument of the diffusion of knowledge, as it was used as a diplomatic language as well.

Writing spread beyond Mesopotamia, and this spread constituted the precondition for the diffusion of other kinds of knowledge from Mesopotamia. Minoan writing appeared in the context of the palace economy on Crete around the turn of the third to the second millennium BCE. Two different systems of writing existed, both undeciphered: the so-called Cretan hieroglyphs and the syllabic Linear A script. These systems almost certainly are the result of stimulus diffusion from Mesopotamia. Writing spread subsequently to the Greek mainland, where it is seen in the Mycenaean culture (which emerged around 1600 BCE); at this time, the Linear A script is replaced by Linear B (ca. 1500 BCE), a largely syllabic script (also including some logograms) for encoding the Greek language. Linear B was used in the administration of the complex agricultural economy of Mycenaean civilization, with tablets from Knossos and Pylos documenting taxes, deliveries of goods, rations for workers and other such administrative practices. By the end of the second millennium the Mycenaean civilization had collapsed, for reasons that still remain unclear, and the Linear B script was no longer used.[35]

On the island of Cyprus, an undeciphered script termed Cypro-Minoan (usually interpreted as having three varieties) was employed in the second half of the second millennium. This script apparently derives from Linear A and is the source of the Cypriot syllabary, which came into use toward the end of the first millennium and remained in use well into the period when Greek alphabetic writing was employed on the mainland, being replaced entirely by the Greek alphabet only in the fourth century BCE.

Current consensus dates the Greek alphabet to around the ninth century BCE.[36] The alphabet was modeled upon that of the Phoenicians. But whereas Phoenician and West Semitic alphabets in general possessed characters only for consonants, the Greek script adapted certain Phoenician semi-vowel characters (known as *matres lectionis*, for example, w, y) as vowels. Phoenician/Greek contact was extensive in the ninth century, and it has been argued that the alphabet shows signs of influence from the Cypriot syllabary, thus suggesting perhaps an origin in Cyprus (where there existed a significant Phoenician presence). A West Greek alphabet constituted the model for the creation of the Etruscan (before 700 BCE), the Latin (seventh century BCE) and Cyrillic (ca. ninth century CE) alphabets. Latin and Cyrillic eventually became two of the most frequently used scripts in the world.

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[34] See chapter 7.

[35] For the spread of writing from Mesopotamia, see (Sasson 1995; Houston 2004; Baines et al. 2008).

[36] For a discussion of the Greek alphabet, see (Woodard 1997; Krebernik 2007a).

3.9 Greek Science and Its Counterparts

Knowledge of Mesopotamian and Egyptian astronomy, cosmology, medicine and arithmetic diffused gradually into the Greek world. Earlier it had diffused into the Persian Empire in the wake of its conquests, a diffusion that in turn influenced the Greeks.[37] We see reflections of this knowledge back around the eighth century in the poet Hesiod, who was influenced by the Phoenican and Hittite cultural traditions and to a lesser degree even earlier in oral Homeric poetry. But it is in Miletus, in Asia Minor, where we find in the late seventh and sixth centuries BCE the first speculative writings in Greek concerning natural philosophy. As a trade city, Miletus was well connected to the developed literate societies of the Near East and thus open to the import of Near Eastern knowledge traditions. Hippocrates, generally considered the founding figure of Greek medicine, came from the island of Cos, only a short distance from Caria, part of the Achaemenid Persian Empire, which also embraced the ancient cultures of the Near East. In this empire, stretching from Egypt to India, Aramaic was the lingua franca. Thus Greek medicine emerged in a multiethnic, multilingual context, in which Near Eastern knowledge concerning healing would certainly have been known.[38]

While Babylonian texts conveyed primarily first-order knowledge, such as astronomical and meteorological observations or particular medical techniques, Greek science turned in a more theoretical direction and authors presented a great amount of second-order knowledge, such as predictive models or methodological reflections that constituted, at the same time, knowledge about observed regularities and knowledge about this knowledge, in particular about its production and validity. This is not to say that the Babylonians did not produce second-order knowledge, but such knowledge is scarcely found in their texts. Possibly the strong state and religious institutional contexts in which Babylonian knowledge was produced allowed for a considerable background of shared second-order knowledge that simply did not need to be documented.[39] In any case, although the Greeks came to acquire Babylonian first-order knowledge in areas such as astronomy, Greek thinkers engaged in new reflection concerning this knowledge and generated the distinctive second-order knowledge that was the hallmark of Greek science, for mathematics as well as for medicine.[40] In fact, the medical theory of four humors may well be considered as the same kind of second-order knowledge as Pythagorean mathematics, with humoral theory offering a unified formula to explain diverse medical data.

Although in Greece, writing constituted an important precondition for the extensive accumulation of second-order knowledge, writing is evidently not a nec-

[37] See (Ray and Potts 2007).
[38] See chapter 8.
[39] Note, however, that the long-term comparison of astronomical observations performed at distant places and at distant times in Babylonia required a control of the meaning of the terms used to describe the recorded events, as emphasized by Graßhoff (chapter 7, section 7.2).
[40] See chapter 8.

essary condition for such an accumulation. In early India, a purely oral culture, reflection upon the sacred Vedas, facilitated by elaborate mnemonic techniques, allowed for the generation of extensive second-order knowledge, best illustrated by the fifth-century grammar of Pāṇini, which consists of an elaborate system of approximately eight thousand rules expressed in highly abbreviated sūtra form that allow for the generation of virtually all word forms of the Sanskrit language.[41]

The spread of Greek science, including natural philosophy, medicine, mathematics and astronomy, can be summed up in five major phases, although knowledge of Greek science traveled sporadically via other routes, resurfacing in many places.[42] In the first phase, science, which began in Asia Minor and Ionia, is relocated to Athens, as the power, wealth and prestige of that city increases. The second phase, which takes place during the Hellenistic period, involves the spread of science to major international hubs, especially Alexandria, Byzantium and Rome. The third phase comprises first the Syriac, the Persian and then the Arabic translation movements.[43] In the fourth phase, Greek science reenters the Latin West, partly via translations from Greek into Latin, partly via Arabic translations, often then in turn translated into Latin. The fifth phase is the recovery of scientific texts in the Greek original by the humanists and subsequent appearance of numerous commentaries both in Latin and in the vernaculars.[44]

In Greece, traditions of natural philosophy and science initially emerged within a polycentric urban context with limited institutionalization before the Hellenistic period. The growth of scientific knowledge was largely sporadic, determined by the interests of a small number of individuals, despite attempts at systematization, such as those by Aristotle and his Peripatetic successors. The institutionalization of science and an attempt at systematic accumulation of knowledge began in the Hellenistic age, but was limited by the dependence on a few large hubs that were not part of a robust network and which constituted critical points of failure (witness the destruction of the library at Alexandria).[45] Nonetheless, Hellenistic science was able to make significant advances in certain areas, such as astronomy, as a consequence of the fact that the Hellenistic world now included Babylonia, and hence Greek thinkers had direct access to Babylonian texts and the knowledge of Babylonian practitioners. In Rome, there was substantial development of new second-order knowledge, especially of a technological variety, but this knowledge was deeply embedded in institutions such as the Roman army, and much of it was not written down. This institutional embeddedness of sophisticated second-order engineering knowledge, that is, generalized knowledge generated from reflection on accumulated practical experiences, together with a consequent lack of motivation to document the knowledge, paralleled the situation earlier in the Persian Empire and earlier still in Babylonia. Roman encyclopedists such as Pliny did, however,

[41] See (Scharf and Hyman 2012).
[42] For an overview focusing on mathematics, see (Szabó 1978).
[43] See also the discussion in Part 2 of this volume.
[44] For an exemplary longitudinal study, see (Renn and Damerow 2012).
[45] For an overview, see (Russo 2004).

assemble a considerable amount of Greek knowledge, as well as knowledge from other sources, and enable the transmission of this knowledge through the European Middle Ages. The encyclopedists, however, were in general indiscriminate with respect to the quality of their sources and presented knowledge in a largely unsystematic fashion.[46]

Greek science failed to develop further as a consequence of the fact that there was no social network sufficiently robust to preserve it.[47] Nonetheless, much of the knowledge, both first and second-order, was preserved as a result of the technology of writing, although it must be noted that the lack of durability of the writing materials necessitated the continual recopying of texts—an activity that required extrinsic motivation. Still, Greek science has been preserved, at least in part, to the present day, and practices of Greek science continued, although in piecemeal fashion, in Rome, Persia, Byzantium, Arabia and Europe, without any complete break. There was, however, little accumulation of knowledge and addition to the body of Greek knowledge before the Islamic period. In general, social conditions were such that a stable and self-perpetuating science did not emerge until early modern Europe. It is telling that Greek science had to be rediscovered so many times; that there were so many renaissances. As we shall see in Part 2, each of them exposed science to a new level of globalization, integrating it with knowledge traditions of other origins.

Science involving second-order knowledge documented in writing emerged in China at about the same time as in Europe, and in a similar social context that was characterized by competing urban centers and competing philosophical schools, such as Confucianists, Sophists and Mohists.[48] Only in the latter school did knowledge about the natural world and methods for justifying such knowledge play a prominent role. The conditions for transmitting this knowledge in China, however, differed from those in western Eurasia. With the emergence of centralized control in China under the Qin Dynasty from 221 BCE, a state-sponsored neo-Confucianist hegemony effectively prevented any philosophical heterodoxy. As a result, in China there was not even the punctuated tradition of the ancient scientific writings that took place in Europe. Thus it appears that scientific knowledge is more effectively preserved by distribution than by centralization. But when surveying the historical and geographic spread of scientific knowledge, it should not be overlooked that, whatever its fate, there is continual evolution of all other kinds of knowledge, so that a rediscovery always constitutes in effect a spoliation, a placing of older knowledge into a completely new context. When Greek science was appropriated in early modern Europe, so much had changed in the meantime—and, notably the technology of writing had diffused, diversified and been

[46] See (Thorndike 1923), see also (Collison 1964).
[47] For a study of Greek culture in terms of network analysis, see (Malkin 2011).
[48] See chapter 11; see also (Renn and Schemmel 2006). A standard reference is (Needham 1988). For a comparative assessement of Greek and Chinese science, see the work of Lloyd, in particular (Lloyd 1996, 2002).

altered by the new technology of printing—that instead of Greek science being reborn, what was born was modern science.

3.10 Interpreting Early History with the Help of a Typology of Knowledge

To approach this historical material systematically, it is necessary to focus on knowledge, even where the archeological record gives us only artifacts.[49] Thus, for instance, a narrow approach that ignores knowledge in the archeological study of metallurgy or ceramics may fail to recognize that apparently different products were created with the same technology, and thus the same knowledge. Moreover, it is not sufficient to treat knowledge as homogeneous, but necessary rather to recognize that knowledge is of radically different types. Otherwise one runs the risk of ascribing anachronistically the reflexivity, distributivity and systematicity of our knowledge to the knowledge of individuals or groups in a particular historical situation. As explained in the introduction, reflexivity characterizes the degree to which knowledge arises from reflection upon, and abstraction from, other knowledge; it ranges from intuitive knowledge to higher-order knowledge, such as scientific knowledge. Distributivity characterizes the extent to which knowledge is shared; it ranges from individual knowledge to globalized knowledge. Systematicity characterizes the degree to which knowledge complexes are integrated and internally organized; whether we deal with packages or systems of knowledge.

Taking these dimensions into account is particularly crucial when assessing the emergence of higher-order forms of knowledge, such as writing, arithmetic and science. Scholars once assumed that the earliest writing must represent language, because they falsely assumed that writing is a context-free, universal means for representing language.[50] In other words, they failed to recognize that these attributes that apply generally to writing today arose from reflection upon the operations made possible by the earliest writing, which was a specific technology associated with particular administrative processes, and which was used only by a small number of scribes who shared a large complex of practical knowledge. Similarly, scholars erred in inferring that the Babylonians knew the Pythagorean theorem from the evidence that they performed certain arithmetic operations that produced results identical to those that we would achieve by applying the Pythagorean theorem.[51] This error arose from the failure to appreciate that the Pythagorean theorem was the consequence of reflection upon operations of this sort and that the type of systematicity achieved in Greek mathematics was a property of Babylonian mathematics as well. A closer examination of the practices of Babylonian mathematics indeed shows that the arithmetic operations associated with computing the area of a triangle were part of a quite different knowledge system. But whereas Eu-

[49] This argument has been emphasized in (Renfrew and Zubrow 1994; Renfrew 2009).
[50] See, also for the following section, chapters 5 and 6.
[51] See (Damerow 2001).

clidean mathematics is a tightly interwoven deductive system motivated by formal procedures of justification, Babylonian mathematics is essentially a looser system of heuristic procedures.

It is also necessary to employ a fine-grained typology of knowledge if one is to study its transfer. Thus until modern science is globalized, becoming a dominant means by which knowledge is transmitted, first-order knowledge travels far more easily than second-order knowledge. Hence Greek astronomers were able to take over the copious astronomical observations (first-order knowledge) of the Babylonians, but from these they constructed their own astronomical theories (second-order knowledge). Babylonian astronomy, inasmuch as it was a system comprising first- and second-order knowledge, was deeply embedded within state and religious institutions that were unique to Babylonian society; thus it could not be adopted wholesale by the Greeks, but rather served as source of individual data constituting first-order knowledge.[52] Ultimately, a typology of knowledge is needed for any account of the history of knowledge that aspires to an explanation of emergent phenomena, such as the rise of science, avoiding teleological fictions that imagine history as inexorably leading to the present-day situation.

3.11 From Practical via Symbolic to Scientific Knowledge

In the early phase of technology transfer, what is transferred is mostly practical knowledge and never technological knowledge proper, as the latter requires representations that enable reflection, which were unavailable in prehistory. Practical knowledge traveled through demic movement and population contacts. Even back in the Neolithic, practical knowledge relating to agriculture reached a regional degree of distributivity. Symbolic knowledge was always available to Homo sapiens in the form of spoken language, but only with the symbolic revolution of the Upper Paleolithic was knowledge symbolically represented in durable media. The technology of writing, which came into being with the creation of the centrally administered state, greatly expanded the potential of symbolic representation by allowing for complex and formal systems of interrelated symbols that could reliably represent knowledge of complex situations. As writing came to be associated with spoken language, the integration of the two symbolic systems made possible the durable and external representation of any sort of knowledge, and radically decreased the degree to which writing was bound to a particular context. With the existence of Babylonian “mathematical” tablets, on which standard operations are performed with unrealistically large numeric parameters, we see a form of exploratory arithmetic knowledge, demonstrating that arithmetic is becoming less context-bound and more autonomous.[53] Such exploratory knowledge constituted scientific knowledge in the sense of higher-order knowledge resulting from reflecting on experiences with the material world. Science in fact emerged when the

[52]See chapters 7 and 8.
[53]See chapter 6.

means for mastering the material world, be they accounting systems or mechanical instruments, were explored for the sake of gaining knowledge, independent of their practical ends.[54]

Originally writing had only a local distributivity, but with time writing as well as arithmetic spread to a regional extent and eventually became globalized.[55] Writing was the technology that allowed the Babylonians to record their first-order knowledge of the physical world and permitted the transmission of this knowledge to the Greeks.[56] The Greeks, inspired in part by knowledge transmitted from Babylonia and elsewhere, constructed theories of cosmology, mathematics, astronomy, medicine and philosophy that comprised scientific knowledge. These complex systems of scientific knowledge exhibited a hitherto unprecedented degree of systematicity. The distributivity of this knowledge was limited to the region of the (expanding) Greek world, but the fact that these scientific systems were written down allowed their transmission to later cultures, stimulating the creation of new scientific knowledge, and ultimately a scientific revolution that eventually rendered science truly global.

3.12 Knowledge Representations in Early History

Just as it is useful to distinguish between different types of knowledge, it is important, for a historical account of its development, to take into account the different forms of representation and their specific repercussions on the structure and spread of knowledge. We therefore first look at some fundamental properties of external representations, that is, their portability, their durability and their reproducibility. Then we consider the opportunities and limitations of early writing. Finally, we turn to some examples from different historical periods of the implications of different forms of representations of knowledge, ranging from first-order knowledge to mental models.

As explained in the introduction, knowledge of any type is always bound to a particular representation, either internal (i.e., cognitive), or external (i.e., in the world). The form of representation always has implications for the structure of knowledge, for the operations that can be performed on the represented knowledge, and for its potential for transmission. External representations of knowledge make possible reflection upon the knowledge represented, which leads to new higher-order knowledge.[57] In fact, much individual knowledge is acquired from shared knowledge that has an external representation. Once knowledge is represented externally, it is subject to transfer in a knowledge economy. Particular knowledge representation technologies shape this economy in different ways since these technologies vary along a set of economic dimensions. Some dimensions that

[54] See (Damerow and Lefèvre 1981; Damerow 1998).
[55] See chapter 5.
[56] See chapters 7 and 8.
[57] See (Damerow 1996).

are important for the transmission of knowledge are portability (can the representation travel, and if so, how fast?), durability (how lasting is a representation?) and reproducibility (how easily can a representation be copied?).

In early technology transmission, the technological artifacts themselves constitute external representations of knowledge.[58] In the case of stimulus diffusion, the artifacts are the primary or only means of transmission. Even in the case where technology is taught, however, the knowledge externally represented in the artifact is of importance. With the Upper Paleolithic symbolic revolution, the first external representations specifically intended to represent knowledge come into being. Formulaic verbal expressions (e.g., legal formulae) are a crucial vehicle for the transmission of the symbolic and technological knowledge of preliterate cultures, such as the Proto-Indo-European culture discussed in section 3.5.

Writing constituted the first external representation of knowledge that was governed by formal semiotic rules.[59] In principle, writing was highly suited to travel, since it was portable, durable and reproducible. The extreme context-dependence of the earliest writing, however, made it difficult for writing to move beyond the particular institutional context in which it was embedded. As writing came to represent structures of spoken language and became increasingly phonetic, its context-dependence decreased and it began to spread widely. Over time, writing came to be employed in an increasing number of text genres, some having a parallel in spoken language and some made possible only by the technology of writing. Media of writing varied, with the clay tablet predominating in Mesopotamia, and papyrus important in Egypt and Greece. These media had important implications for the durability of the knowledge represented.

In Babylonian science, while first-order knowledge was represented in writing, second-order knowledge was represented mainly in institutions and was thus less portable. Greek science represented both first- and second-order knowledge in writing, thus lending portability and durability to its second-order knowledge.[60] Knowledge of technology often was not sufficiently represented in writing such that the knowledge could not travel without the technological artifacts themselves, which functioned as representations of additional knowledge. Moreover, the practical knowledge of practitioners was often not written, with the consequence that it was lost. Artifacts such as the balance and the gnomon were constructed primarily by means of practical knowledge, but reflection upon these objects led to a higher-order knowledge, with reflection upon the balance and lever, for instance, leading to the balance-lever mental model, which could be applied to such apparently different objects as the oar of a boat.[61] The emergence of specialized forms of writing of a diagrammatic nature allowed knowledge of certain technologies to travel in the absence of the technological artifacts. A striking early form of the diagram is

[58] See chapter 4.
[59] See chapters 5 and 6.
[60] See chapters 7 and 8.
[61] See (Renn and Damerow 2007, 2012).

found in Babylonian field plans, which encoded, among other knowledge, knowledge about the geometric computation of areas.[62] There are also both Babylonian and Greek maps which are the external representations corresponding to internal mental models of space. A significant innovation in Greek mathematics was the lettered diagram, which was crucial in the transmission of the knowledge system of Euclidean geometry.[63] Still, this knowledge depended on shared practical knowledge regarding the ruler and compass construction. Later, we find diagrams of different sorts playing an increasingly important role in the representation and transmission of technological and architectural knowledge. Even machines can be designed as external representations of mental models, with the Antikythera mechanism (second century BCE), which was an elaborate mechanical computer designed to calculate the position of celestial bodies, being the most celebrated and spectacular example from antiquity.[64]

3.13 A Typology of Transmission Processes

After having considered the typology of different forms of knowledge and that of its external representations, we now turn to the characteristics of transmission processes. Knowledge transmission processes vary along three basic dimensions. The first is mediation: is the knowledge transmitted through direct personal contact or through external representations? In immediate transfer, the principal external representations are ephemeral—speech and action. The two main processes of immediate transfer are imitation and instruction. In mediated transfer the external representations may or may not be explicitly designed to represent knowledge. Stimulus transfer is a paradigmatic case of transmission via a representation not explicitly designed to represent knowledge, while transmission by writing is a paradigmatic instance of the other case. The second dimension is directness: for the transmission process considered, was the knowledge transmitted directly from end to end, or were there relays? The third dimension is intentionality: is the knowledge transmitted intentionally or accidentally?

Transmission processes must always be studied within the interaction sphere of the transmitting and receiving actors constituting an epistemic network. A historical background condition is the varying mobility of actors, be they individuals, social groups, or societies. Receivers of knowledge should not be conceived of as passive, since they may resist the transmitted knowledge or appropriate and adapt it to their own knowledge in an equilibration process.[65] The transmission of individual items of knowledge or relatively specific knowledge complexes occurs much more frequently than the transmission of large systems of knowledge. In the words of Cyril Stanley Smith, "a human culture, existing at the apex of a long chain of

[62]See (Damerow 2012).
[63]See (Netz 1999).
[64]See (de Price 1974; Freeth et al. 2006; Freeth 2009).
[65]See chapter 14.

historical selectivity, cannot easily incorporate large chunks of another" (Smith 1977, 84). Knowledge may also be so embedded in culturally specific institutions that it is difficult to extract and hence difficult to transmit. Or the processes of extraction may so radically change the structural relations of the knowledge to other items of knowledge that the knowledge extracted is transformed into new knowledge. Another type of embeddedness is found in complex codes (semiotic systems) that depend on meta codes (that is, rules from outside the representational system).[66] Transmission processes are not simply either successful or not, but always involve selection and transformation; thus writing becomes a selective force in the transmission of knowledge, as what is not written is usually lost.[67]

In prehistorical knowledge transfer, both immediate and mediated processes must have played a role. Long-distance transfer was almost certainly by relay. Stimulus diffusion is an instance of a mediated but accidental process. Even when direct transfer took place, however, we cannot overlook the significance of the technological artifacts themselves in knowledge transmission. The importance of technological artifacts continues into Babylonian and Greek science and continues to play (an often ignored) role even in present-day science.[68] In the case of oral transmission, both instruction and imitation play a role; and we can infer from present-day cultures where bodies of knowledge are transmitted orally that bards first served as apprentices to a master. The transmission of orally encapsulated knowledge through time and space is an instance of transmission by relay.

Although writing was not initially a means for the transmission of knowledge, it began to assume that role quite early and became the dominant means for the mediated transmission of knowledge from the second millennium BCE on. Since some writing materials, such as papyrus, were of limited durability, texts needed to be copied, another instance of relay transmission. The transmission of knowledge via writing required the transmission of the knowledge of how to write, typically by instruction. As writing spread to different cultures, which spoke different languages and/ or had different media of writing available, the technology was adapted to local conditions. We see this adaptation, for example, in the spread of cuneiform to Elam or Anatolia (to write Hittite), or the spread of the Phoenician alphabet to Greece. Such a process of transmission followed by adaptation to local conditions can also be seen in prehistoric metallurgy and ceramic technology, which was transmitted, but then employed for the making of products markedly different from those made elsewhere.[69] In the ancient world, scientific knowledge spreads intermittently, since it can lie dormant in writing, with a Greek mathematician, for instance, picking up a problem from a mathematician who lived decades or even centuries earlier.

[66]See chapter 21.

[67]See the extensive discussions of the concept of transformation in (Renn and Damerow 2007; Damerow and Renn 2010; Böhme et al. 2011).

[68]See, for example, the discussion in (Daston 2000).

[69]See chapter 4.

3.14 From the Early History of Knowledge to the Origins of Science

Let us briefly summarize the early history of knowledge and its long-term consequences. Sociocultural evolution inherently involves knowledge that is efficacious, either with respect to the physical world or with respect to the social world. Once external representations of knowledge that are intended to represent knowledge are exchanged, there can be said to be a knowledge economy. At first this knowledge economy was almost completely tied to the underlying economy of labor. For example, literacy was closely correlated with socioeconomic status, and in Babylonia astronomical knowledge was pursued for agricultural and legitimatory ends, so that the pursuit of astronomical knowledge was ultimately motivated by economic concerns.

But when institutions devoted to the production and exchange of knowledge emerged that were emancipated from other labor, the knowledge economy became in principle decoupled from the economy of labor, although there some degree of entanglement always remained. The emergence of institutions centered around the production and exchange of knowledge made first exploratory knowledge and then science possible, as knowledge could now be pursued for the sake of means rather than ends. In the ancient world, we see several incipient beginnings of science. But epistemic evolution had not yet begun, because there was a severely limited number of hubs of knowledge production, and the network linking these was both fragile and inefficient. Only with the rise of science in the early modern period, economic and social conditions allowed for a robust and scale-free network sustaining the knowledge economy. At this point, the labor economy became increasingly dependent on the knowledge economy, and eventually, change in human society became driven by epistemic evolution, giving rise to socioepistemic evolution although the layers of sociocultural and biological evolution persisted.

Human sedentariness, together with the technologies that sedentariness enabled (e.g., metallurgy, ceramics) was a contingent historical development. The economic structure of sedentary societies, however, generated the capability for and the impulse to expansion, exploration, contact and borrowing (accumulation of knowledge).[70] Thus when sedentariness emerged, it began quickly to spread, transporting a package of knowledge as well. Sedentariness spread both from the West and East, effectively allowing for the transmission of knowledge throughout the whole of Eurasia, with transmission impeded in certain places by geographic obstacles.

The centrally administered state arose in Mesopotamia together with the technologies of writing and arithmetic. These two technologies sprang from the same origin, that is, from large-scale administrative experiences, but soon grew widely divergent.[71] These technologies had two reflective consequences: the formation of

[70] For the spread of knowledge before sedentariness, see (Sahlins 1972). For discussions of the neolithization process, see (Cauvin and Watkins 2000; Hodder et al. 2001; Kozlowski and Aurenche 2005).

[71] See chapter 6.

arithmetic concepts and the formation of metalinguistic awareness. Once writing came to represent language, it caused reflection upon language, and this reflection in turn altered patterns of use in language, thus restructuring language. Internalization of the technology of writing created a mental model of writing that could be applied to diverse contexts. Thus the Babylonians saw “heavenly writing” in the skies and priests “read” organs in extispicy. Later, the model allows authors from Augustine through the early modern period to consider a “book of nature,” and today we apply the model in contexts ranging from the transcription of DNA to the “read” and “write” operations of computer I/O.

Although writing is probably not a necessary condition for scientific knowledge, in the Greek world science developed through the reflective potentials offered by writing and transmitted geographically and historically by writing. The history of knowledge is a layered history, in which more recent knowledge is built upon successive layers of older knowledge. Thus Greek science rested on writing, a technology that had once served narrow ends of civic administration. The earliest writing, in turn, presupposed knowledge of even earlier symbol systems, as well as the practical knowledge of creating materials suitable for writing on and with. Thus “weight” is a second-order concept that emerges from reflecting on the knowledge gained by the operation of weighing objects with a balance, a technology developed toward the end of the second millennium in Babylonia and Egypt, that exploited metallurgic knowledge many millennia older.[72] Our discussion began with the story of simple craft technologies, a story that has often been told with no reference at all to knowledge. But these ancient craft technologies provided mental models that aided the Greeks in the creation of their science. Thus in cosmology, Anaximander likens the cosmic rings to wheels, and in mechanics the balance is employed as a mental model that explains all machines that allow small forces to achieve large effects. In this layered history, we see quite concretely the path from technology transfer to the origins of science.

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[72] See (Damerow et al. 2002; Renn and Damerow 2012).

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Chapter 4
Technological Transfer and Innovation in Ancient Eurasia

Daniel T. Potts

4.1 Introduction

The pre-modern transfer of knowledge within Eurasia had to contend with a complex set of both physical and mental obstacles. Deserts, mountains and oceans had to be crossed, but so too did language barriers and ingrained traditions of cultural praxis. The fact that knowledge transfer occurred in spite of a seemingly long series of hurdles that had to be overcome has often been attributed to some fairly potent "vehicles"—Buddhism, the and Jesuit missionary activity, to name just a few of the more obvious ones which operated in the literate past. But archaeological investigations have shown that knowledge and technology transfer can also be documented in the pre-literate past.

The enormity of the Eurasian landmass, not to mention the multiplicity of linguistic and cultural entities inhabiting it, have rarely, if ever, been viewed by archaeologists as insurmountable impediments to long-range contacts between the many cultures inhabiting it in antiquity. Journals such as *Eurasia Septentrionalis Antiqua: Journal for East European and North-Asiatic Archaeology and Ethnography* (1927–1938), published by the Finnish Society of Archaeology, or the more recent *Ancient Civilizations from Scythia to Siberia: An international journal of comparative studies in history and archaeology* (established 1995) bear witness to the fact that archaeologists have been thinking on an inter-continental scale for many, many years. Nor have such studies been limited to discussions of shared art styles or artifact types. The possibility that technologies and "knowledge complexes" may have spread from one part of the continent to another during the past has long been entertained and in this sense the globalization of knowledge has, both implicitly and explicitly, been on the agenda of many archaeologists. The difficult problem of discriminating autochthonous innovation and independent invention from the complete or partial adoption of an allochthonous technology has been a particular concern of scholars working in Europe and Asia and in what follows I shall present several cases of technological transfer in ancient Eurasia. First, however, I should like to say a few words about how transfer and transmission, or what is often termed "diffusion," have been dealt with by archaeologists and others concerned with the ancient world.

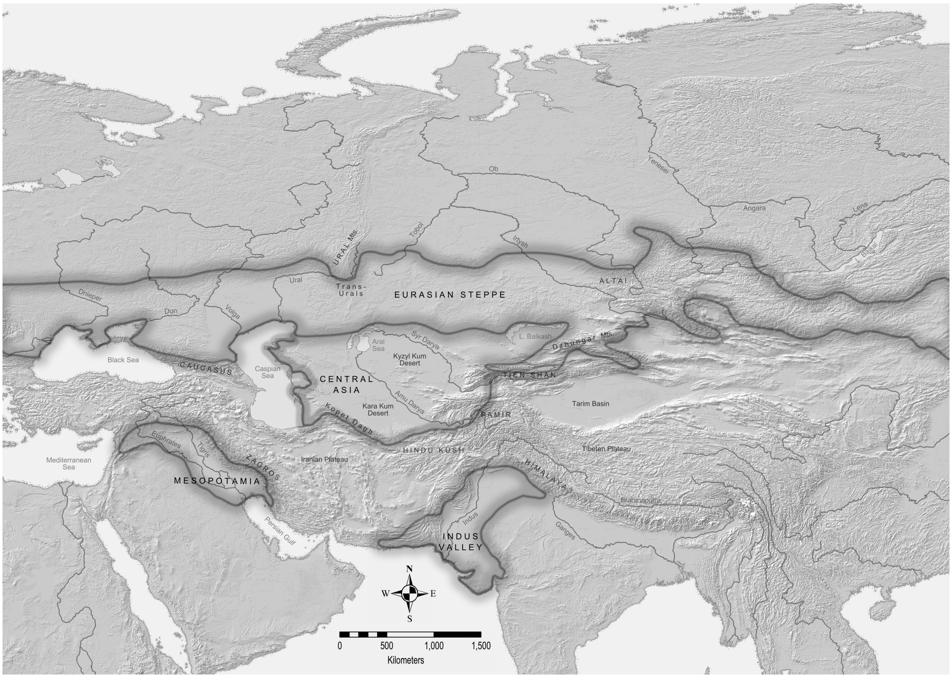

Figure 4.1: Map of Eurasia showing the regions of greatest relevance to this chapter (Frachetti and Rouse 2012, Fig. 36.1). With kind permission of the authors.

4.2 Terminology and Ideology

As part of its 300th birthday celebrations in 1936, Harvard University convened a symposium entitled "Independence, Convergence, and Borrowing in Institutions, Thought, and Art." On that occasion, V. Gordon Childe, widely esteemed as one of the greatest prehistorians of the twentieth century, offered what he entitled *A Prehistorian's Interpretation of Diffusion* (Childe 1937). A voracious reader, Childe was more aware than most of archaeological discoveries made throughout the vast area extending from the Pacific coast of China to the Atlantic shores of Ireland and Iberia. Despite the fact that he boasted more than a passing acquaintance with dozens and dozens of regional cultures across Eurasia, Childe was an unapologetic proponent of diffusion, something he described as "essentially the pooling of ideas, building up from many sides the cultural capital of humanity" (Childe 1937, 4). In their crudest form, many pre-Childean discussions of diffusion had striven to prove that entire civilizations owed their origins to the external stimulus of an advanced society (e.g., Mesopotamia > Indus Valley; Mesopotamia

> Egypt; Mesopotamia > China; Phoenicia > North America). More sober discussions of diffusion were often preoccupied with cultural contacts that effected the spread of superficially obvious stylistic traits, such as patterns on painted pottery.[1] This fixation on epiphenomena or superstructure, as Marx would have called it, rather than core technologies and infrastructure, was not characteristic of Childe, an avowed Marxist. Indeed, Childe's Harvard lecture cited examples of technological transfer ranging from printing and paper to the steam engine before indulging in the more traditional, broad brush look at links between civilizations in Egypt, Mesopotamia and the Indus Valley evinced by portable items of material culture (ceramics, stone vessels and cylinder seals) that were accumulating rapidly during the pre-war era.

Several years after Childe delivered his lecture, the American anthropologist Alfred Louis Kroeber published a very different paper on what he termed "stimulus diffusion." There he examined what might be called "partial" or "selective" technology transfers, citing, among other things, the case of porcelain manufacture in eighteenth-century Europe (Kroeber 1940). The existence of high quality porcelain in China and its export to Europe, he argued, created the stimulus for the local invention of the technology to replicate, at lower cost, the same sort of end product. This entailed everything from the identification of suitable kaolin deposits to the design and construction of appropriate kilns. As Kroeber wrote:

> The consequence is that we have here what from one angle is nothing else than an invention. Superficially it is a "parallel," in the technical language of ethnology. However, it is equally significant that the invention, although original so far as Europeans were concerned, was not really independent. (Kroeber 1940, 2)

In this context Kroeber's views anticipated those of the eminent MIT metallurgist Cyril Stanley Smith who, almost forty years later, stressed the importance of studying "why a society will not absorb things into which it is brought into contact," observing:

> A human culture, existing at the apex of a long chain of historical selectivity cannot easily incorporate large chunks of another, though occasionally small things can seep in without opposition and later interact to form a nucleus that can grow by rearranging the connections between things already present. (Smith 1977, 84–85)

Viewpoints like Kroeber's (and later Smith's) became increasingly unpopular during the 1960s and 1970s as anti-diffusionist views, sometimes fueled by chauvinistic, nationalist sentiment, gained ground. A quarter of a century later, while

[1] For a useful review of the main proponents of diffusionism, see (Trigger 1989, 150–160), particularly Oscar Montelius' *ex oriente lux* views of European cultural development and its Near Eastern antecedents; cf. (Montelius 1899).

shots were still being fired in the ideological battle between indigenous evolution and "stimulus diffusion," the concept of the "interaction sphere" (Caldwell 1964) appeared as a kind of theoretical bandage to heal the wounds of the diffusion debate. With its implicitly egalitarian outlook, suggesting equally weighted interactions between contemporary constituents of a cultural mosaic, interaction spheres were conceptualized as "the areal matrices of regular and institutionally maintained intersocietal articulation" (Binford 1965, 208). Lewis R. Binford suggested that the "comparative structural and functional analysis of interaction spheres [...] allows us to define, quantify, and explain the observation [...] rates of cultural change may be directly related to rates of social interaction" (Binford 1965, 208). Such a perspective, however, smacks of scientists in the laboratory dispassionately viewing the interactions of cultures as conglomerations of atoms that can be studied in some kind of closed atmosphere. Not only is there no causality implied in the interactions that take place, there is no intent, directionality or hierarchy in the interactions charted. As Lightfoot and Martinez rightly noted in describing developments in Anglo-American archaeology during the 1960s and 1970s, "the theoretical underpinnings of New Archaeology, with its focus on cultural ecological models, closed systems, and antidiffusionism, were not conducive to the study of cultural interactions" (Lightfoot and Martinez 1995, 474).

It was not just theoretical underpinnings that were to blame for the increasingly geographically narrow views of archaeologists. Combined with an attitudinal prejudice against anything that smacked of migration and diffusion (against which Härke (1998) wrote eloquently), the explosion of scientific data (in part due to excavation and survey, in part a product of the "publish or perish" syndrome that emphasizes quantity over quality) made it more and more difficult for anyone to achieve the kind of synthetic oversight of Eurasian archaeology which Montelius, Childe or Grahame Clark (1969) were able to achieve. Symptomatic of the difficulty of controlling the data necessary to address broad-scale questions of technology transfer in antiquity was the failure of most scholars at a 1978 symposium in Aarhus, entitled "The origin of agriculture and technology—West or East Asia?" to come anywhere near to achieving their aims (Muhly 1981). As J. D. Muhly noted in reviewing the conference (no proceedings were ever published):

> [...] no one wanted to draw far-reaching conclusions or to develop wide-ranging theories. This is in keeping with the spirit of the times: we are in an age of cautious and detailed specialization, an age suspicious of hypothetical speculation and the "great theory." [...] Theories based upon influences from outside a given archaeological culture, theories using traditional ideas about migration and diffusion, are now anathema to most prehistorians and field archaeologists. [...] In this sense it could be said that everyone systematically ignored the theme of the symposium, and indeed such charges were made during the course of the meeting. In defense, I believe that most scholars would agree that we are simply not in a position to discuss the influence of East upon

> West or vice versa […] We are still too busy trying to figure out what was going on in a particular area to worry about the possibility of cross-cultural contacts. (Muhly 1981, 126–127)

Many archaeologists and ancient historians working today would probably agree with Muhly as they continue, thirty years on, "trying to figure out what was going on." Yet it could be argued that focusing on the concrete outcomes of technological praxis—for example, harvested cultivars, decorated weaponry, or painted pottery, whether at the macroscopic or the microscopic level—is neither the only nor the best way of investigating intercultural contact and technology transfer. The deficiency in such an approach is that it almost always ignores the technology behind those outcomes—the cultivation, irrigation and harvesting practices used to create the crop; the smelting and casting techniques used to fashion the metal; and the clay preparation and firing methods used to make the pottery. I suggest that an examination of the technologies underpinning cultural production offers a viable alternative to the study of the epiphenomena themselves and a potential way forward in trying to move beyond the impasse highlighted by Muhly's comments.

4.3 Inverting Kroeber's Stimulus Diffusion Model: From Polemics to Applied Science

In his discussion of stimulus diffusion, Kroeber was at pains to describe situations in which a technical problem had been solved in one culture in order to replicate a foreign product through home-grown ingenuity. In the case of porcelain, the idea had spread to Western Europe, as had examples of the finished product, but everything else, from appropriate clays to kilns, had to be found and/or invented *ab novo* in the European context. In antiquity, I suggest that we look for instances where exactly the opposite occurred, where the technologies spread, enabling the production of distinctive, culturally "local" products that would otherwise escape notice and not arouse any suspicion of inter-cultural contact. Acknowledging the distinctiveness of ways of doing things, as opposed to end-products, is somewhat akin to identifying the difference between "cultural patterning" at the level of praxis and "technological style" as its external or "formal, extrinsic manifestation," a concept advanced thirty years ago by the MIT materials scientist and historical metallurgist, Heather Lechtman. Using a linguistic analogy, Lechtman observed: "The oft-cited distinction used by linguistics between langue and parole is precisely that distinction between pattern and style," observing that:

> Style is the manifest expression, on the behavioral level, of cultural patterning that is usually neither cognitively known nor even knowable by members of a cultural community except by scientists who may have analysed successfully their own cultural patterns or those of other cultures. (Lechtman 1977, 4)

Although these concepts are applicable to any sort of material culture, Lechtman was writing in the first instance about prehistoric metallurgy and it is to a metallurgical example that I wish now to turn.

4.4 A Eurasian Problem: Western Influences in the Development of Chinese Metallurgy

Nineteenth-century scholars, including the Assyriologist W. St. Chad Boscawen (1854–1913), the Sinologists Albert Étienne Jean Baptiste Terrien de Lacouperie (1845–1894) and E. H. Parker (1849–1926), and the missionary Joseph Edkins (1823– 1905) wrote learned and, today, largely forgotten works attempting to demonstrate everything from the Western, more particularly Babylonian or 'Aryan' origins of ancient Chinese language and writing to agriculture, astronomy, weights and measures.[2] One of the most contentious and emotionally charged topics in the history of metallurgical scholarship concerns the origins of and external influences exerted upon China's earliest bronze technology. In light of recent DNA analyses on population affinities in Inner Asia that strongly suggest contacts between Western and Eastern populations in the first millennium BCE (Comas et al. 1998; Bennett and Kaestle 2006), metallurgical analysis is also potentially vital to an understanding of the earlier phases of population dynamics as well as technology transfer.

Briefly stated, there exist wildly divergent views on the extent to which Chinese metallurgy was or was not influenced by contact with the West (i.e., Central Asia, the Near East and/or the Mediterranean). In 1954, Lauriston Ward asserted that there were bronzes in the Shang period:

> such as the bronze ceremonial vessels [...] like nothing in the West [...] There are, however, other bronze artifacts from Anyang which are of convincingly Western type, namely helmets (cf. Early Dynastic forms in Mesopotamia), socketed celts of European Late Bronze Age type, and socketed spearheads with two loops for binding, like those occurring in Europe in the Middle Bronze Age. (Ward 1954, 138)

Two years later Max Loehr argued very strongly for external, Western influence on the earliest development of bronzes in China (Loehr 1956). As one reviewer noted, Loehr definitely tightens the chain of evidence and inference concerning Mesopotamian, Steppe, and Siberian influence in much of the early Chinese bronze art (Kaplan 1957, 378).

Contrast these positions with that of Ho Ping-Ti two decades later. In an unabashed *apologia* for the independence of Chinese civilization, Ho rejected any suggestion of foreign influence from the West; argued for the autochthonous origins

[2]See, for example, (Edkins 1871; Parker 1883; Terrien de Lacouperie 1885; Boscawen 1888; Terrien de Lacouperie 1894).

of "the primitive copper metallurgy of the loess highlands of China"; and derived the later Shang bronze industry from it (Ho 1975, 221). In his review of Ho's *Cradle of the East* and Noel Bernard and Tamotsu Sato's *Metallurgical Remains of Ancient China* (1975), the distinguished MIT metallurgist Cyril Stanley Smith wrote extensively about the problem of diffusion vs. independent invention. As he noted:

> It is clearly true that metallurgy did not creep slowly and continuously into China from its boundaries, but, taking a world view, can we be sure that the nuclear suggestion did not come from somewhere else by a route that left no record of its passage? Bernard gives a world map on page 16, which combines his own data with those of Colin Renfrew, who has argued strongly for similar independence of the earliest metallurgical developments in the Balkans. The map shows no fewer than six "independent regions of early metallurgy," with China the last of all to appear. This reviewer, while granting that technical elaboration occurs differently in different locations, finds it impossible to believe that the basic ideas of metallurgy were so easy to come by ad nuovo. It is incredibly difficult to invent anything really new, while information, albeit garbled and incomplete, is easily carried by travelers. Does transmission have to leave a record? […] On a very detailed scale, there would be little evidence beyond intangible style for links between the sites noted in China itself. One must take into account the stage of development involved in a transfer, the stage both of the technological details and of the receiving culture. Rather than postulating independent invention, it seems to me that the interesting questions concern how, with many nuclei in the air, a strong culture can incorporate into its own fabric as compatible only very few of the things it hears of, while resisting most suggestions that come to it from continuing if superficial contacts with neighboring and sometimes remote peoples. Regardless of whether the first idea of making and shaping metals arose spontaneously in China or came from outside by a barrier passing process akin to quantum-mechanical tunneling, there can be no question that the subsequent development of metallurgy was indigenous. The furnaces, the crucibles, the molds, and the almost exclusive dependence on casting, even of iron when it appears, all bear the unique stamp of that great civilization.[3]

In 1993 Donald Wagner leapt to the defense of Ho, Bernard and Sato, launching a determined attack against diffusionists like Smith (and Joseph Needham, see below). After admitting that transmission does not have to leave a record, he argued:

[3] (Smith 1977, 81–82), cf. (Chang 1978).

> The anti-diffusionists cannot hope to provide the sort of positive proof that the diffusionists may, under fortunate circumstances, be able to provide. It is therefore incumbent on the diffusionists to provide positive empirical evidence. Broad untestable opinions […] are not useful in a scientific discussion. (Wagner 1993, 33)

The polemical positions adopted in this debate are obvious. Full of post-colonial outrage, one camp is morally affronted by the very notion that a civilization the size of China should owe anything to outside influence, while some hard-nosed metallurgists and historians of science cannot let go of the sneaking suspicion that somewhere along the line, the esoteric, technical lore of bronze-working, so unlikely to have been "invented" in the second millennium BCE in a Chinese vacuum, must have diffused from the west. Recently, however, a whole host of new data has emerged from research conducted by Chinese scholars who seem to be undaunted by nationalist rhetoric in the face of scientific evidence. The prime scholar in this new movement is Mei Jianjun whose Cambridge Ph.D., published in 2000, provides a wealth of important analytical results and previously unpublished material from Xinjiang that must alter the views of even the most die-hard indigenous evolutionist.

4.5 New Perspectives on an Old Problem

Mei's research has isolated two important sets of external linkages in the earliest copper and bronze-using cultures of Xinjiang. The first group concerns the Afanasievo Culture of southern Siberia (Minusinsk and Altai regions). This consists of ceramics from the Ke'ermuqi cemetery in the Altai region as well as similarities in funerary customs (monumental structures on the surface above graves, skeletal position and copper objects) between Afanasievo sites and Gumugou in the eastern part of the Tarim basin (Mei 2000, 58).

The second and, in my view, far more important source of linkages is with the Andronovo culture, a name given to a vast conglomeration of related cultural complexes extending from the Urals in the west to the Yenisei in the east, and from the forest-steppe in the north to the Pamirs in the south. Stockbreeding, including horse, cattle and sheep, was economically important to Andronovo communities, as was bronze metallurgy. The presence of Andronovo-type ceramics at Central Asian sites in Turkmenistan and Uzbekistan with calibrated C14 dates of c. 1900–1750 BCE, coupled with evidence for the diffusion of Andronovo material culture from west to east, suggests that the origins of the complex in the Urals might be placed around 2000 BCE.

Mei has conclusively demonstrated the infiltration of Xinjiang by characteristic elements of Andronovo (steppe Bronze Age) material culture, including metals (weaponry, tools) reflecting "a wide range of metallurgical technologies, such as casting, forging, annealing and cold-working […] during the latter part of the second and the early first millennium BCE."[4] These have been documented at Aga'ersen, Gumugou, Weixiao and Sazi in the Yili-Tacheng district of northwestern Xinjiang (Mei 2000, 60). The presence of copper sulphide inclusions in the Tacheng objects, in particular, has suggested that copper sulphide ores were being smelted, a more complex procedure than the smelting of copper oxide ores and one likely to have involved the exploitation of local copper ores in Xinjiang (Mei 2000, 48). Mei has suggested that the "matte smelting process" was being followed, whereby the ore was partially roasted so as to convert the iron sulphides into oxides; the roasted ore was then smelted to produce matte (molten metal sulphide phase); the matte was roasted; and the roasted matte was reduced to yield copper. In comparison with the direct reduction of copper oxide ores, the process of smelting sulphide ores is far more complicated.[5] Interestingly, Song Dynasty (960–1279) texts describe this process in detail and direct evidence from the first millennium BCE is provided by slag found at Nulusai which has been analyzed by Mei (2000, 55–57).

Where might such complex technology have originated? The predominance of true bronze in this corpus, with tin levels between 2–10%, "suggests a cultural affiliation of the Tacheng objects with the Andronovo complex" (Mei 2000, 46). As Chernykh noted, Andronovo bronzes containing 3–10% tin comprise "90–100 per cent of the metal artifacts in assemblages from the various regions of the community" (Chernykh 1992, 213). This, he suggested, owed its origins to yet more westerly innovations:

> The original stimulus for metallurgy and metalworking in the Andronovo community came from the west, from the region where the productive centers of the CMP (Circum-Pontic Metallurgical Province), which was in collapse, or the workshops of the CMP-EAMP (Eurasian Metallurgical Province). (Chernykh 1992, 214)

Other metals besides bronze may have been involved as well. Seven years before Mei's dissertation appeared, Emma Bunker published an important paper on gold in ancient China where she pointed to the presence of a cast gold earring, "penannular with one funnel-shaped terminate" at "Liujiahe in Pinggu, Beijing district, east of the Taihang mountain range in Hebei" as well as bronze earrings of the same type elsewhere in Hebei and at Lower Xiaojiadian culture sites in Liaoning, which are "a diagnostic artifact universally associated with Andronovo material found to the northwest in the Altai region of southern Siberia, in Tomsk in western Siberia, and further west along the Amu-Darya River near the foothills of the Ural Mountains" (Bunker 1993, 30). While chronologically contemporary with the Shang period (trad. 1766–1123 BCE), these sites were culturally non-Shang and showed "indigenous regional characteristics" as well as the aforementioned

[4] (Mei and Shell 1999, 573), cf. (Mei et al. 1998).
[5] Cf. (Pigott 2002).

evidence of contact with the outside world. In Bunker's opinion, the location of the sites in Hebei

> gave them access to Inner Asia via the ancient 'Fur Route,' a complex trading network that crossed Eurasia long before the opening of the more southerly 'Silk Route.' The Fur Route ran in an eastward direction north of the fiftieth parallel from the Caspian Sea to southern Siberia, and then southward to ancient China and its border areas via the Amur Valley. The existence of this route explains the presence in Hebei of an Andronovan type of funnel-shaped earring. (Bunker 1993, 31)

As Joseph Needham wrote in 1964:

> I believe that the longer the time which has elapsed between the first successful achievement of an art or invention in one place and its appearance in another, the more difficult it is to entertain the idea of a purely independent invention. (Needham 1964, 403)

Although he was referring to the much later, westward diffusion to Europe, via Iran, of Chinese cast-iron technology,[6] the same applies in the case of bronze much earlier, albeit in the opposite direction. The far greater antiquity of bronze metallurgy in the Near East, which dates to the early to mid-third millennium BCE, the complexity of the copper sulphide reduction process, and the timing of the first Andronovo contacts with western China, all combine to provide several necessary preconditions for a transfer of technology, followed without any doubt by centuries of creative, indigenous invention as Chinese metallurgists developed a uniquely Chinese bronzeworking tradition.[7]

In the future, additional technical studies that throw light on the precise techniques used by the earliest metallurgists in Xinjiang will be important to undertake since it is clear that once the "Chinese" (Shang) bronze industry appears, it is very different, in most technical respects, from that of the Andronovo complexes (Sherratt 2006, 45). While arguing vigorously for a common metallurgical ancestry, Smith was always at pains to stress the uniqueness of Chinese bronze production which eschewed the cire perdue or lost wax technique in favor of "the sectionalism of the molds, the alternating levels of positive and negative décor, the coring and the casting-on" (Smith 1977, 82).[8]

In conclusion, despite the rejection of the perspectives of diffusionists like Max Loehr by scholars such as Ho and Wagner, it is striking that forty-five years before Mei's dissertation was written, Loehr had prophesied:

[6] Cf. (White 1960; Wertime 1964); on Chinese iron, see esp. (Wagner 1999).
[7] Cf. (Sherratt 2006).
[8] Cf. (Linduff 2005) who suggests that even this may be a Eurasian rather than a Chinese invention.

> If any culture in the West did convey elements likely to promote metalworking in North-China, it must have been the Andronovo culture. (Loehr 1956, 86)

4.6 Perspectives on the Study of Technology Transfer in Eurasian Metallurgy

At the beginning of this paper I reviewed some of the history of archaeological and anthropological debate over independent invention vs. diffusion in general terms, and later some of the more specific debate generated in the case of Chinese metallurgy and its origins. Several sociological aspects of the science involved in this entire field of study, not mentioned earlier, are worth noting.

First, achieving anything like a "Eurasian" perspective is incredibly difficult, given the multiplicity of sources, in a multitude of languages, that must be assessed. Archaeologists who have dealt with Central Asian material are acutely aware of the enormous difference in the potential for creative scholarship between the Soviet and the post-Soviet eras. Access to Soviet archaeological literature was extremely difficult for Western scholars prior to the 1980s, when active cooperation with Soviet scholars began a trend which has obviously greatly accelerated since the collapse of the Soviet Union. One can look at a work like Chernykh's *Ancient Metallurgy* in the USSR, which was written shortly before the end of the Soviet regime, and marvel at its scope, but at the same time recognize that Chernykh's Laboratory for Spectral Analysis, in the Institute of Archaeology (Academy of Sciences, Moscow), enjoyed a privileged position in being able to undertake tens of thousands of analyses on objects found throughout the Soviet Union. In many ways, this political situation, coupled of course with the genuine curiosity of Chernykh and his colleagues, permitted the construction of a Eurasian perspective that was all but impossible for anyone outside of that country to achieve.

At the same time, Chernykh's horizon ended at the borders of Mongolia and Xinjiang, an artificial eastern barrier inhibiting what ought to have been a truly Eurasian perspective. One must remember not only the often adversarial history of Soviet-Chinese relations, but the almost complete dearth of contemporary Chinese archaeological data in the West during much of the twentieth century, a situation only ameliorated by K.C. Chang (Yale and later Harvard University) via his mainland contacts. Neither North American and European scholars, nor Soviet ones, had access to the sort of data that Mei has now made available.

One can, therefore, only marvel all the more at a scholar like Max Loehr whose prescience in divining the likelihood of an Andronovo contribution to early Chinese metallurgy now seems extraordinary. For not only was Loehr's view informed largely by his studies in China during the years 1940–1949, when he was a researcher and later director of the Sino-German Institute in Beijing (Cahill 1989), but it is apparent that, notwithstanding the great difficulty of accessing Soviet archaeological literature, he was familiar with the little that was available outside of the Soviet Union on Andronovo matters as well. What Chernykh called the Eurasian Metallurgical Province really only became a reality when Jianjun Mei's analyses shone the spotlight on Xinjiang and its Andronovo connections, but the vast architecture of such a concept was already apparent in Loehr's mind by the early 1950s.

4.7 Fellow Travelers in Eurasian Transfers

In my opinion, the metallurgical example of technology transfer in Eurasia outlined above is bolstered by other instances of cross-cultural interchange which reflect comparable inter-regional contact. Four such cases seem particularly apposite.

Tin – the sine qua non of Andronovo metallurgy, has long been a problem for Near Eastern and European archaeologists, but recent studies, some of which were unavailable when Chernykh was writing, have identified significant tin sources in Uzbekistan, Tajikistan and Afghanistan (Boroffka et al. 2002). During the early second millennium BCE, i.e., precisely the same time as Andronovo expansion to Xinjiang is thought to have been taking place, we have cuneiform sources from Mari on the Euphrates, near the modern border of Syria and Iraq, that throw exceptional light on traffic in tin. In particular, the fact that Mari's rulers solicited tin from the king of Elam, a powerful state in southwestern Iran (Potts 1999), and then passed some of it on to their client kingdoms further west in Syria (e.g., Qatna), shows us how tin from Central Asia could travel all the way to the Mediterranean. If that sort of movement was possible in an east-west direction, there should have been no technical impediment to the same sort of movement of tin in a west-east trajectory.

Bactrian camel – it is now clear that the Bactrian camel, which originated in Mongolia (Baotou) and Xinjiang (Lake Barkhol) and had nothing to do with the ancient land of Bactria at all (northern Afghanistan/ southern Uzbekistan), was already present in the West by the early second millennium BCE, having reached Anau in Turkmenistan by the mid-fourth millennium BCE (Potts 2004). By the mid-third millennium Bactrian camels figured prominently in the iconography of Central Asian (Bactrian and Margianan) stamp seals and by the early second millennium (c. 1750–1700 BCE) one appears on a cylinder seal in Old Syrian style, now in the Walters Art Gallery in Baltimore. Bactrian remains are attested at the Andronovo site of Aleksejevskoje in Tatarstan; at Il'inskaja gora, a Karasuk culture cemetery in the southwest Ural foothills; and at Gorodsk, north of Kiev, in the Ukraine, all contexts dating to the second millennium. The most probable use of these Bactrians was as stud animals since Bactrian-dromedary crosses are extremely strong, capable of carrying 500kg, double the load of a dromedary. These "super cargo" carriers of the second millennium BCE (and later) would, without any doubt, have facilitated trans-continental travel across Eurasia at precisely the time when Andronovo cultural groups are thought to have been spreading into Xinjiang with their metallurgical technology.

Figure 4.2: Herd of *Camelus bactrianus* in the Nubra Valley, Ladakh, India. Photo: John E. Hill, with kind permission.

Wheat – there is a growing body of palaeobotanical data in the form of charred wheat grains, now known at "all of the early Xinjiang oases" (Chen and Hiebert 1995, 287) including Gumugou, Shirenzi, Lanzhouwanzi and Qunbake. At Gumugou, where preservation was excellent, wheat was found in a grass basket close to the head in a number of graves, a practice strongly reminiscent of Andronovo funerary practice at sites like Alekseevka in southern Siberia. In Xinjiang wheat was being grown in deltaic fans where flood irrigation could be easily practiced in a manner reminiscent of that followed in the oases of Bactria and Margiana (western Central Asia). Even if "the *idea* of oasis-based agriculture" reaching Xinjiang from western Central Asia remains unproven (Thornton and Schurr 2004, 85) there is no doubt that wheat was an introduction from the west. Additional data comes from Donghuishan in western Gansu where domesticated, carbonized wheat remains have been dated to c. 3000–2500 BCE (although based on C14, it is not clear whether the dates were calibrated or not). Again, little detail is available (no indication of what type of *Triticum*), but Chinese archaeologists believe this must have been an import from the west via the Hexi Corridor (Li 2002, 180). Wheat is, therefore, a cultivar which may well provide a parallel to the example of metallurgical technology transfer discussed above. It may even have moved in association with metallurgical technology.

Horse – As Jansen et al. (2002, 10910) stress:

> Although there are claims for horse domestication as early as 4500 BCE for Iberia and the Eurasian steppe, the earliest undisputed evidence are chariot burials dating to c. 2000 BCE from Krivoe Ozero (Sintashta-Petrovka culture) on the Ural steppe.[9]

It is tempting to associate the transfer of metallurgical technology via Andronovo cultural complexes with the spread of both the Bactrian camel, heading west, and the horse, heading east from the Ural steppes and Central Asia (Levine 1999; Jansen et al. 2002), to which we may add the chariot to China (Shaughnessy 1988). As Muhly noted twenty years ago:

> Piggott now places the first development of [...] chariots within the Timber Grave/Andronovo cultures of south Russia, between the Ural mountains and the Irtysh river and dating to ca. 1700–1400 BCE (calculated from uncalibrated dates which, on the basis of the MASCA 1973 calibration, would be 2060–1600 BCE). Innovations there spread both to the west (as far as Mycenaean Greece) and to the east, where chariot burials from Shang Dynasty China have almost their exact counterparts in those from the waterlogged tombs at Lchashen on Lake Sevan in the Armenian SSR. (Muhly 1988, 89)

Speaking of these latter finds, which were compared in great detail with Shang-period chariots in China, E. L. Shaughnessy wrote:

> If we now compare the technical characteristics of the Chinese and Trans-Caucasian chariots, I think there can be no doubt as to their typological similarity, or even identity. (Shaughnessy 1988, 206)

Bunker has suggested that the Fur Route, discussed above, may have been one of the routes whereby elements of foreign technology "such as the chariot, could have been introduced into the ancient Chinese world from cultural centers to the west" (Bunker 1993, 31).

4.8 Conclusions

The work of Chernykh, Mei and Li, and its evaluation by metallurgists like Pigott, suggest to me very strongly that the pendulum has swung well away from the adamant rejection of diffusion evinced by Wagner and Ho, in favor of a much

[9] Cf. (Levine 1999).

more Eurasian perspective in the tradition of Loehr and Smith. The fact that two Chinese scholars are in the vanguard of this new appreciation of Andronovo influences in Xinjiang is, I believe, highly significant, suggesting that a new generation of Chinese scholars is more interested in divining the technological secrets of bronzeworking, wherever they may have originated, than in forcing hollow claims for priority based on geography and political affinities. In this respect, the demise of the Soviet Union and the opening up of China have contributed enormously to the attempt to understand technological transfer at a Eurasian scale. Nevertheless, there are still many issues that require attention if the case for significant Andronovo (early second millennium BCE) contacts with Xinjiang, and via the Hexi or Gansu Corridor (a narrow strip of territory leading southeastwards, past the western end of the Nei Mongol Autonomous Region, into Gansu), with the Chinese heartland, is to move beyond the realm of possibility into that of probability. Perhaps foremost amongst these is the analysis of ancient mtDNA from the regions where the technology transfer discussed here is thought to have occurred.

At the present time the available studies of mtDNA from Eurasian populations[10] do not include material contemporary with the period of postulated Andronovo-Xinjiang contact. Li Shuicheng has emphasized the anthropologically mixed nature of the Yanbulak cemetery in Hami, a site located in eastern Xinjiang at the head of the Hexi or Gansu Corridor. Mongold and Caucasoid individuals were said to be present, with Caucasoids in the minority (Li 2002, 175). Further west, at Lop Nor (Luobunoer/ Lopnur, still in Xinjiang), the individuals found in a cemetery dated to the early second millennium BCE (1710–1535 uncal. BCE) were said to be entirely Caucasoid.[11] The status of these anthropological analyses is unclear.[12] New, multivariate craniometric work by Brian Hemphill suggests that, in the earliest Bronze Age population of the Tarim Basin does not manifest admixture from either the steppes (Andronovo) or the oases (Bactria, Margiana) of western Central Asia, and that not until 1200 BCE did significant gene flow from groups in the Ferghana Valley (Uzbekistan) and the Pamirs occur.[13] The DNA studies undertaken to date are promising, but clearly there is a serious need for similar studies on older genetic material.

Of course, on their own such studies do not merely answer old questions, they pose new ones. Did the posited diffusion of metallurgical technology from the West to the East, via the Andronovo-Xinjiang cultural/geographical regions, necessarily involve the movement of large enough numbers of specialists and their families to be detectable in the bio-archaeological record? Was the "technological package" brought back by indigenous peoples who had travelled to the West,

[10]For example, (Comas et al. 1998; Bennett and Kaestle 2006).

[11]Cf. (Thornton and Schurr 2004, 93–94), citing mtDNA research by Cui Yinqui at Jilin Univ. suggesting "the earliest mummies of the southern Tarim Basin grouped closely with the modern Sardinian and Basque samples without evidence for any mtDNA contribution from the east."

[12]They were conducted by Chinese anthropologist K. Han and published in China in the 1980s and early 1990s. For references, see (Li 2002, 181).

[13](Hemphill and Mallory 2004); cf. (Thornton and Schurr 2004, 90–91).

thus resulting in no genetic admixture detectable in their DNA? These and similar questions—which go to the very heart of longstanding debates on diffusionism—continue to resonate in a world where globalization, both ancient and modern, is now regarded as a fact of life.

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Chapter 5
Writing, Language and Textuality: Conditions for the Transmission of Knowledge in the Ancient Near East
Eva Cancik-Kirschbaum

5.1 Introduction

Among the means of symbolic representation writing is a relatively late achievement in the history of mankind.[1] Its direct and indirect relations to knowledge are beyond doubt. But especially with regard to the principal cultural manifestations of knowledge—namely forms, representational structures, transfer processes and their societal implementation—the prominent place of writing is manifest: bound to knowledge, writing may come to play a role in nearly all dimensions of social life. In order to analyze this situation the concept of *Kulturtechnik*[2] may prove useful as it refers not only to the language-related aspects of notational systems, but also to the diagrammatic, iconic, and operative features of the textual artifact. Of particular interest is the role of writing in the *transmission of knowledge*, not only as a recurring field of application in all the dimensions named above, but also in terms of *language* (in the double sense of *langue* and *parole*) as subject to and object of *writing* within the processes involved.

In the context of this paper some of the effects and consequences of notational systems as *Kulturtechnik* are looked at against the historical background of the Ancient Near East—well known as the realm of the cuneiform script as well as the cradle of the alphabetic writing systems.[3] In the following, I adopt a broader perspective in the hope of contributing to questions such as: What terms and concepts are useful in evaluating the role of writing for the emergence and development, production and accumulation, diffusion and concealment, detachment

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[1] This chapter has benefited from the critical comments of P. Damerow, M. Hyman, J.C. Johnson, M. Krebernik and G. Selz.

[2] The notions of the term *Kulturtechnik* adopted here are based on a concept, which guides the research of the Hermann von Helmholtz-Zentrum für Kulturtechnik at Humboldt-University, Berlin, especially the DFG-funded research-group “Bild – Schrift – Zahl” (2001–2007). See (Krämer and Bredekamp 2003), esp. the introduction; furthermore (Grube et al. 2005).

[3] A sound overview of the repeated incidences of invention can be found in (Houston 2004), for general information, see (Raible 1991b). For an interesting new empirical wrinkle vis-à-vis the early transmission toward the Eastern Aegean, see (DeVries 2007, 96–98); the date of transmission is discussed controversially in (Sass 2005).

and re-implementation, destruction and loss of knowledge? How can the process of "text-artifactualization" be related to the process of globalization of knowledge?[4]

Since the beginning of the Neolithic the vast landmass situated at the intersection of Africa, Asia and Europe has seen important cultural innovations, such as agriculture and the domestication of animals, settled communities, long-distance trade, urban life, and the early state. Among the many technologies would constantly transform these societies, from the simplest to the most complex crafts, the invention of several systems of graphic and/or object-based mnemonic devices, which allowed for depersonalized communication, led to the invention of a notational system. Toward the end of the fourth millennium BCE the successful conception and implementation of a coherent writing system, a script, can be observed. The technique first used was incising; later a reed-stylus was impressed into tablet-shaped pieces of moist clay. Due to the nail-shaped impressions characteristic of the later phases of this writing system, the term cunei-form (from Neo-Latin *cuneus*) was coined in eighteenth-century Europe.

Initially this system reproduced with a limited set of signs *clusters of information*, namely the primary significant of the message (not the actual speech-act) to be conveyed. Over time it underwent a process of controlled intrinsic (internal) extension and modification, aimed at adapting the tool to the ever-changing needs of different cultures and societies. Parameters such as ergonomics, the avoidance of ambiguity and velocity, among others, must have played an important role in this process. Whereas these parameters are difficult to assess, another parameter's consequences were more straightforward: "phonetization,"[5] a term referring to the moulding of the writing system to better reproduce the elements of speech, led to substantial changes in the structure of the notational system. The quantity and the quality of written records multiplied, allowing for broader patterns with regard to form and content. The cuneiform script was adapted to various linguistic contexts, as ethnically heterogeneous cultures with their different languages made use of the writing system. This not only resulted in the diffusion of a useful technical tool and the further development of its structural and functional components, but also allowed for the controlled (and often not so controlled) diffusion, dissemination, detachment, and reimplementation of knowledge stored in writing. Thus knowledge could be detached from its original context and travel in space

[4]The term "globalization" does not lend itself easily to premodern societies and early civilizations. However, the notion of "global" is relative, to be looked at under the particular emic perspective of a given society. Thus the kings of Sumer and Akkad assumed the titles "king of wholeness, king of the four quarters of the world," emphasizing their sovereignty as "global." Moreover, if related to this "scaled globality" the conditions in the Ancient Near East meet in a correspondingly scaled modification the definition in Blossfeld and Hofmeister (2006, 8): "We define globalization by four interrelated structural shifts: (1) the internationalization of markets in terms of labor, capital and goods and decline of national borders (2) intensified competition through deregulation, privatization and liberalization (3) accelerated spread of networks and knowledge via new communication and information (4) the rising importance of world markets and their increasing dependency on random shocks."

[5]For a critical view, cf. (Whittaker 2001).

and time encoded in a particular means, namely writing. However, it must not be forgotten that encoding has its counterpart in decoding. Access to knowledge stored in writing requires a host of techniques for unpacking its content: apart from physical access, which might be limited to elites, initiates, and the like, these would include first of all reading, but also the mastering of language and terminology. And last but not least the general conditions of historical contingency are a major aspect of writing. Writing systems are part of a given cultural continuum. Societal and institutional derivatives such as literacy and education, as well as their epistemological consequences, for example, the differentiation of knowledge and the formation of scientific activities, are to be seen as closely related phenomena.

5.2 Writing, Language, and *Kulturtechnik*

From a present-day perspective the impact of writing on the history of knowledge seems fairly obvious: literacy is considered a basic feature of modern knowledge-based society. Indeed, the degree of alphabetization within a given society defines a meaningful parameter regard to its prospects for future development. In the sciences an important segment of knowledge relies heavily on written records and documentation. And, last but not least, writing has come to serve as a powerful paper-tool, see, for example, chemical formula. However, at the same time, the end of an era has been announced; the Gutenberg-galaxy is fading away due to the accelerated growth of integrated means communication, as for example, the IT-based technologies. These new technologies are not only dependent to a high degree upon writing as a tool, but also the complex nature of the epistemological technique encoded in the mechanics (and the grammar) of *writing*, which, together with other techniques, enabled their very development. The transformation of an old-fashioned tool and its derivatives into these new forms and media will undoubtedly affect the nature of *writing*, but the extent of this transformation on *writing* itself remains an open question. Yet the characteristic ambiguity of *writing*, its Janus-nature, namely as both “means” and “media” at the same time, has been part of its history from the very beginning.

Within Mediterranean antiquity and even beyond, two more-or-less opposed attitudes toward writing and literacy can be observed. “Language” as well as “writing” have each been a subject of interest in the Greek tradition, for example, mirrored in an extensive philosophical, grammatical, and linguistic discourse (Frede and Inwood 2005). On the one hand, writing is often depicted as a divine gift of dubious value, leading to the degeneration of mind and brain. On the other hand, it is considered an instrument of power, access to which was restricted to few and its use highly esteemed. These at first glance competing assumptions interact in the concept of writing, enabling the representation of speech. The high value of the spoken word, its creative, and even magical force is fused with the binding force of the written word. In terms of a one-to-one relation of *phonê* “sound” and *graphê* "symbol," script came to be understood primarily as a *representation* of the spoken utterance, a vehicle or container for speech. This emphasis on the language-related attitudes toward writing, as seen in the Greek tradition, reflects to a certain extent one of the most prominent discourses on writing and its use (Villers 2005).[6] Due most probably to the impact of the (partly misunderstood) Aristotelian legacy on European grammatological thought, this particular strategy of certain writing systems, namely the transcription of *speech*, has been given particular attention (Trabant 2006). Together with the no less influential assumption of a superior position for alphabetic writing as developed in rabbinic as well as in Christian religious thought, a general tendency toward a phonocentric as well as alphabetocentric bias characterizes European attitudes toward writing systems in general (Busi 2001; Bandt 2007).

Another assumption, which has had a strong influence on the analytic perspective adopted in most investigations of writing, is the idea that literacy is closely linked to cultural evolution in one form or another.[7] This notion can also be traced back not only to classical antiquity, but even beyond, becoming an increasingly attractive model since the eighteenth century. For instance, Rousseau claimed in his *Essay on the Origin of Language* that the three main stages of human evolution are paralleled in the evolution of writing systems:

> These three ways of writing [i.e. logographic, syllabic, alphabetic, ECK] correspond almost exactly to three different stages according to which one can consider men gathered into nation. The depicting of objects is appropriate to a savage people; signs of words and of propositions, to a barbaric people, and the alphabet to civilized people. (Rousseau 1966, 17)

The claimed relation between literacy and culture has led to a vast literature, with the primacy of the alphabet (particularly in terms of its supposedly Greek origin) as a major focus.[8] The consequences of this model did lead to some interesting hypotheses: not only has alphabetic literacy been credited with the genesis of

[6]With regards to the overall success of the technique, this aspect of writing is certainly of utmost relevance. Indeed, linguistic knowledge as most relevant for the creation of a writing system as such is perhaps the earliest form of systematically, but indirectly encoded, knowledge. This holds especially true with regard to early forms of linguistic thought, which become visible in the organizational mode of writing systems (Cavigneaux 1989). A typical feature is, for example, the systematics of sign encoding: primary objects (such as animals, goods, and so forth), actions (encoded in verbs such as "to deliver") and actors (names, titles, functions) vs. less relevant parameters such as modality or aspect. For a (debated) systematic approach as regards Egyptian hieroglyphs, see (Goldwasser 1995).

[7]Examples given typically relate to the East Asian and European traditions, but similar concepts can be found in other cultural contexts.

[8]See (Diringer 1948; Gelb 1963, 201; Havelock 1982, 11). The effects and outcomes of other successful solutions in the history of writing were generally left aside, or judged to be incomplete forerunners or precursors. With regard to the history of Ancient Near Eastern writing systems, see (Michalowski 1990, 57–59; Cancik-Kirschbaum 2005, 2006; Cancik-Kirschbaum and Chambon 2006); see also (Cancik-Kirschbaum and Chambon forthcoming).

democracy, it has been argued that the advancement of modern scientific thought is a particular result of the alphabetic mode.[9] Last but not least, writing and literacy have played a central role in twentieth-century theories, explaining social and cultural change as either linked to cognitive attitude and mentality[10] or to the evolution in technologies of communication[11] These ideas have certainly stimulated a great deal of discussion, but they have also been subject to particularly detailed and heavy criticism (Halverson 1992).[12] Thus, occidental alphabetocentrism has not only prejudiced theories of language and culture in the past, it continues to leave its stamp on the philosophy of language and on the archaeology of media, even when systematic research in non-European writing systems clearly points to approaches that recognize the internal principles of each kind of writing system rather than fitting them into a single evolutionary sequence.[13]

Meanwhile the rather limited perception of writing as a system confined to the encoding of phonological strings[14] is intensively discussed and a significantly broader perspective on the relation(s) between speech and writing has been developed. The rather narrow analytical framework of earlier investigations, focusing mainly on encoding (rather than decoding) has been significantly enlarged by shifting focus to the aspect of "reading" as an important, or even the most significant access to the parameters governing writing systems of all kinds (Olson 1996). David R. Olson summarizes these outcomes as follows:

> First, writing is not the transcription of speech but rather provides a conceptual model for that speech. […] Second, the history of scripts is not, contrary to the common view, the history of failed attempts and partial successes toward the invention of the alphabet, but rather the by-product of attempts to use a script for a language for which it is ill suited. Third, the models of language provided by our scripts are both what is acquired in the process of learning to read and write and what is employed in thinking about language; writing is in principle metalinguistics.[15]

I will be returning to the issue of metalinguistics and later, primarily in terms of text as a model for language.[16]

The perspective that Olson and others have adopted here was reinforced when the semantic range of the term "writing" itself came under discussion. The so-called non-linguistic, second-order aspects have been recognized as central to the

[9]With varying shifts of emphasis, among others, (McLuhan 1962; Goody and Watt 1963; Havelock 1976, 1982; Ong 1982; Goody 1986; Halverson 1992).
[10]Such as (Lévy-Bruhl 1923; Lloyd 1983; Tambiah 1990).
[11]See (Innis 1950; McLuhan 1962; Havelock 1982).
[12]A sound overview is given in (Olson 1996, chap. 3).
[13]See (DeFrancis 1989; Harris 1989; Koch and Oesterreicher 1996; Olson 1996; Petterson 1996; Krämer 1997; Stetter 1997; Mersch 2000, 2002).
[14]See, for example, (Gaur 1987; Harris 1989).
[15]See (Olson 1996, 89); see furthermore (Herriman 1986; Astington and Olson 1990).
[16]See further (Selz 2000).

operative potential of writing. Consequently language-neutral and iconographic aspects have complemented the language-based concept of writing. Aesthetic and perceptual aspects came into focus. The capability of (any) writing system to record speech more or less adequately is but one perspective to be looked at. In addition to transcribing speech, several other aspects of writing systems can be delineated as follows: (1) The iconicity of writing, namely techniques of displaying information in the form of graphs, diagrams, tables, that is, the foremost visual level of written communication that extends largely beyond verbalized narrative. (2) As a more general (but not identical) category here the textual layout as such has to be taken into account. Within the facture (the elements of external formal appearance) of a given text a particular type of information is encoded, which partly coincides with the content of written text, and partly supersedes it. As an example, just compare from this perspective a bilingual dictionary with the instructions manual for an electronic device. As regards the operating principles, the dictionary gives a horizontal layer (translating a lexeme from one language into the other language) and a vertical layer (e.g., multiple semantic contexts). Referentiality is mainly intrinsic, that is, within the dictionary, one term has one (or multiple) equivalent(s). Yet the instructions refer directly to the device, its operating mode is principally unidimensional (except perhaps for special cases), referentiality is mainly extrinsic, that is, from the text toward the external device. (3) The *dynamics* is not only inherent in the textual content itself, but actually evident by the use of writing as such. These so-called operative potentials come into being if the text provokes a reaction and stimulates new insights (Gramelsberger 2001). In a more indirect form, they are active when, for example, *writing* serves as a model to describe or understand formerly unrelated phenomena, for example, when writing is used as a metaphor to explain the patterns of the heavenly bodies ("celestial writing"), or when divination is perceived as a communicative system operating with a scriptural terminology, for instance, the gods writing in the liver of the sacrificial animal (Cancik-Kirschbaum 2005). At one (unknown) moment Mesopotamian scholars were even aware of the hermeneutic potentials of writing: the shape of a cuneiform sign (sign-iconsim) was loaded with meaning relating to its denotational reference. In its most elaborate form, this theory gave access to universal understanding: world and cosmos became represented in writing, thus knowing how to "read" the signs meant being able to decode the universe.[17]

The overall configuration of these aspects suggests a notion of *writing* that allows for a multi-perspectival profile, that is, a profile not restricted to the usual interpretation of writing as just another denotationally specified format for the phonological components of language. Although the aspect of *turning written* (viz. the totality of parameters and conditions, which interfere in the process of transforming phonetic articulation into another medium, namely graphic articulation, the term *entextualization* (Silverstein and Urban 1996) covers part of this phenomenon) is of particular importance within the historical and epistemo-

[17]See (Maul 1999); further on the role of sign-shapes and understanding, see (Finkel 2010).

logical process under discussion, it is complemented by other aspects of similar significance. To cover these different perspectives, the term *Kulturtechnik* is used here, as it encompasses all features that add to the specific profile of writing, and consequently to our understanding of its role within the globalization of knowledge. Other ways of documenting and transmitting knowledge are covered by this term too: paper tools (e.g., chemical formula), geometrical representations, sketches, diagrams, maps, mathematical and logical symbols, and so forth. Moreover, *Kulturtechnik* is not limited to writing, but also encompasses purely iconic systems, such as images, as well as numerical systems.[18] Consequently writing is to be understood within the concept of *Kulturtechnik* as the systematic handling of symbolic representational systems.[19]

The invention or introduction of writing is to be regarded as a response to societal needs and developments, such as (bureaucratic) control, the need for calculation, prestige, ceremony, and representation, to mention some of the most evident stimulators.[20] The (historically discernible) solutions to meet these needs are characterized by varying strategies of problem solving, depending on the preconditions and the setting of such a process (Ehlich 1980). The consequences of the implementation of a sophisticated means of graphic communication clearly differ according to the given historical, societal, and cultural circumstances. A *scriptural turn* which leads to the invention and establishment of a pristine writing system will differ from subsequent transformations and modifications of the particular system adopted by a previously non-literate society. The term *Kulturtechnik* underlines the anthropological (cultural) nature of writing. The installation of writing in a society is a conscious act, thus biological metaphors such as "genesis," "emergence," and the like are less helpful.

> On the contrary, although the discovery of some of its principal elements (representation as the most important) might have occurred accidentally, its constitution as a system is always the consequence of intentional coordination. This holds true not only for de novo scripts, but also for the introduction of (newly invented or existing) scripts within a given society. (Cancik-Kirschbaum and Johnson forthcoming)

At the same time writing incorporates a potentially creative force, insofar as it can take on a leading role in the creation or internal development of cultural segments (or subsystems), such as religion, law, politics, economics, and so forth. But one must bear in mind, at the same time, that once writing has determined

[18]Difficulties arise with the metaphorical use of "writing" as, for example, with "genome sequences (and the relevant terminology (transcriptase ...)" and other fields).

[19]The acknowledgment of both the linguistic-discursive *and* the iconic-operative aspects of writing has considerable consequences as regards the analysis of the genesis of writing systems (Cancik-Kirschbaum 2012).

[20]See (Postgate et al. 1995; Morenz 2004).

parts or even the entirety of these social spheres, other traditions will have been transformed, suppressed, or even forgotten. That is to say, the creative process associated with the implementation of a written tradition is inevitably linked to process of selection with regard to the existing repertoire of knowledge.

5.3 Writing and Textuality: Different Levels of Representation of Knowledge

In the Ancient Near East, writing as a means of graphic communication originates within the sphere of bureaucracy and economic administration.[21] It is a society of increasing complexity that not only determines the field(s) of application of the new technology, but also provides for its institutional setting.[22] Graphic and pseudographic recording systems, precursors to writing, emerge in Mesopotamia during the late fourth millennium. The creative force of this invention was not immediately visible, as it was embedded in a wide range of innovations, stimulated by the needs and settings of a complex society. These first samples of early systems of graphic communication were neither without functional parallels nor were they designed as autonomous, self-explanatory devices. They were constituted within a sophisticated repertoire of externalizing tools, practices, mnemonic devices, and communicative techniques, for example, the use of seals conveying hierarchically sequenced information, clay as a medium (in the literal sense of the term),[23] or the "trace" (of a reed, a finger-imprint on any object, even textiles) as a record of processes of en- and decoding. As graphic manifestations these systems relate to iconography; as regards the serialization of concrete information they parallel numerical notation. In Michalowski's words:

> Seals, potters' marks, painting and craft ornamentation, tokens, bullae, numerical tablets, and other designs – these must be seen as parallel systems of communication. (Michalowski 1990, 59)

Multiple technical and conceptual stimuli—some of which certainly elude us—seem to coincide in the formation of a new *Kulturtechnik*, viz. *writing*. How exactly these converge into the elaborated system that shows up toward the end of the fourth millennium remains open to speculation. But, as the term *Kulturtechnik* also indicates, we have to allow not only for *stimuli* and *development*, but also for experiment, error, invention, and systematic elaboration.

Early Mesopotamia and its adjacent regions furnish detailed, although evidence of the pristine establishment of several writing systems. The process of

[21] It goes without saying that this special field is itself part of and was shaped according to the outlines of its supporting cultural background, by its perception of the world and its governing principles, see (Selz 2000, 171).

[22] See (Nissen et al. 1993; Englund 1998; Damerow 1999; Selz 2000; Krebernik 2002; Glassner 2003; Damerow 2007).

[23] For calculation, see chapter 6.

adapting writing systems to particular languages has repeatedly taken place between the third and the first millennium BCE, as various civilizations adopted the cuneiform so as to enable record keeping in their own language. And last but not least several entirely new, formally and typologically different systems of writing were conceived:

1. Alphabetic script: attested in its earliest examples in the eighteenth century at the Western periphery of the cuneiform-based societies and strongly influenced by the Egyptian writing tradition. It occurs in not only linear (letter-based) applications, but also in two cuneiform modifications (namely Ugaritic cuneiform in the fourteenth century, and Old Persian cuneiform in the sixth century).[24] Interestingly enough for Old Persian the "moment of invention" is attested in a contemporary royal inscription that reads: "And Darius, the king, says: By Uramasdas favor, I made this inscription otherwise, in 'Aryan,' which did not exist before, on clay-tablet, as well as on leather.[25] "Aryan" is the language of the Old-Persian script.

2. Glyphic script: used in Anatolia from the fifteenth century onwards to encode the Luwian language in a mixed system with syllabic and logographic components. It is attested mostly in representative monumental inscriptions in stone, but also in seal-inscriptions and on lead strips.

The actual history of all these different writing systems—whether cuneiform, linear, or hieroglyphic—can be taken one representation of the globalization of knowledge, namely knowing "how to write." Indirectly they are linked to metalinguistics, as they are all examples of a more-or-less efficient link between language and a completely different representational system.

The process of *transmission* takes on a special nuance if seen within the vital sphere of cultural contact. The transfer of a writing system together with its didactic material on the one hand, and the transformation of the system in order to adapt it to the concrete needs of the receiving community on the other hand, fostered an awareness of linguistics and grammatical thought. These became explicit not only in translation (bilingual and trilingual versions of a text), but also in the use of vocabularies (up to four languages!) and bilingual lexical lists. Early attestations of this use can be seen in twenty-fourth-century Ebla in northwestern Syria, and it is certainly not an accident that this takes place at the periphery of the heartland of cuneiform, Mesopotamia. The transmission of the cuneiform writing system and its subsequent grammatological adaption to a new linguistic context has taken place several times during the history of cuneiform writing.[26] A particular phenomenon within the multilingual and multiscriptural continuum of Ancient Near Eastern societies is *alloglottography*: a text is written

[24] The so-called alphabetic technique co-existed with the traditional systems of writing and finally replaced them.
[25] Translation, see (Rubio 2006, 38–39).
[26] Cf. for example, (van Soldt 2010).

Figure 5.1: Assyrian scribe writing Akkadian in cuneiform script on a clay tablet next to an Assyrian scribe writing Aramaic in alphabetic script on a piece of papyros or leather (pergament). Reconstruction of a Wall Painting from Til Barsip, eighth century BC, Louvre.
(Photo Florentina Geller)

(down) in a language different from the language in which it was originally uttered and/or in which it is intended to be read. The translational process involved is immediately linked to the level of writing and based on a deep knowledge of the interdependences of language(s) and writing system(s). This principle may first be observed when the first (known) transfer-process of the cuneiform writing system took place, from Sumerian to Akkadian: as a self-conscious process this system has been reconstructed for the trilingual inscriptions of the Achaemenid kings of Persia (Rubio 2006).

Looking at the various languages transmitted via the practice of writing, we must bear in mind that not only written language and spoken language have left their traces, but also the degree to which a writing system as such is bound to render the internal and external linguistic features of a given language. Thus writing systems differ considerably with regard to the implementation into (or of) the grammatical system of the languages they convey—on the phonological, morphological, and syntactical level (Eisenberg 1989). This applies differently to the different types of writing systems. Grammatical and orthographic depth is an explicitly language-orientated characteristic of writing systems. The term "depth" relates to the third dimension of writing-besides the two dimensions of the written surface and the extension of textual record on the surface. This third dimension takes up the vital process of permanent change as a typical feature of living languages. Under certain conditions, these changes are made visible in the writing systems, for instance, by means of changing orthographic habits.[27] This holds especially true for the moments where the cuneiform system was adapted to another linguistic context, such as written Akkadian, a Semitic language with the sign system used for Sumerian (a language of unknown linguistic affiliation), written Hittite, an Indoeuropean language with the sign system used for Akkadian, and so on. The difficulties in adapting a writing system to any other language are not easily overcome: the set of graphemes must be made to correlate with the respective sound inventories; the morphological structures and regularities of individual languages are more or less smoothly harmonized with the possibilities of a logo-syllabographic sign system. But it is exactly this difference, this *formal dissimilarity* (they are "aligned" through functional similarties, but the formal incompatibilities must still be overcome) between the giving and the receiving part that becomes productive in the Near Eastern history of writing. Lacking contemporary (past) theoretical discourses about the phenomenon, the history of those translation processes may be studied only indirectly, namely through the changing patterns of the cuneiform scripts. These changes turn out to be an archive of the difficulties, of the—successful and sometimes unsuccessful—attempted solutions to the formal dissimilarities between the two systems. Thus, for example, in order to render Akkadian adequately, the receiving writing system had to elaborate its phonographic capacities (Greenstein 1984). The grammatological features linked to orthographic depth also make the coexistence and overlay of languages visible, as is the case with Aramaic and Akkadian during the first millennium: here particular features of spoken Aramaic leave their traces in the writing of Akkadian in cuneiform (Streck 2001).

Once writing has been installed as a system of recording, following orthographic norms and conventions, the adaptation to the manifold chaos of language and speech-act is obviously achieved by direct usage. As to the incentives that

[27]So, for instance, morphematic (that is, focusing on the semantic identity of a word) writing conventions in alphabetical or syllabic systems will heavily influence phonetic adequacy. The recent orthographic reform of German, for example, made use of that principle. For instance, the word for the stem of a plant used to be spelled STENGEL, but this has been changed to STÄNGEL to clearly designate its etymological derivation form "STANGE" (tiny pole). But the phonetic reality is that we all articulate the |e| rather than the |ä|. On the other hand, syllabic or phonographic renderings of originally morphophonemically structured writings (typically, logogramms, one word = one sign) may considerably hinder the process of perceptive understanding.

may at first have stimulated this widening of the primary disposition of the recording system one can only speculate. To an important degree, they are based on conditions that have been observed for such processes leading to expanded use in later epochs:

1. particular demands on the recording of proper names (personal names, place names)
2. of terms and designations in a foreign language
3. a widening of the sphere in which writing is used, that is, a widening of the circle of users as well as of specific contexts of usage (literature!)
4. the presence of several languages side by side as a phenomenon of limited "processes of globalization"
5. the elimination of ambiguities and orthographies prone to misunderstanding.

Be this as it may, in Mesopotamia the implementation of new "manners of writing" is evidently regulated by the alternate play of availability and need. This process led to a situation, masterfully described by Piotr Michalowski:

> The early history of cuneiform might be characterized as one of an uneasy adaptation of an autonomous communication system to accommodate natural language. By the middle of the third millennium the new system was capable of representing full utterances, but it was still something of a mnemonic device to the extent that no attempt was made to represent with precision all aspects of language. Only kernel elements were noted, and these were not inscribed in the order in which they were read. Thus a verb, which in later writing might have numerous affixes, would only carry one or two prefixes. The reader was expected to provide the missing elements and to unscramble the signs into their proper sequence. The graphic elements needed for fairly accurate phonological representation of Sumerian language were all in place, […] but that was not the goal of the recording system. (Michalowski 1994, 25)

By the second quarter of the third millennium, this process seems to have reached a certain optimum: the proportion of logographic and phonetic-syllabographic graphemes becomes stable. Even "frozen" ways of writing begin to appear, that is, ways of writing in which a convention of writing stands in opposition to the phonetic reality. While Sumerian texts are mostly rendered in a morpheme- and word-centered manner, in second-millennium documents we find also syllabographic renderings—thus a "syllabic orthography" existed. But, as Cooper puts it:

> Despite the obvious capability to write texts entirely phonetically […] the resistance to a purely phonetic orthography which would have greatly simplified these writing systems suggests that certain ideological biases in favour of traditional logophonetic writing were working

> against Gelb's 'principle of economy aiming at the expression of linguistic forms by the smallest possible number of signs.' (Cooper 2004, 91)

An interesting situation arises toward the end of the cuneiform cultures, more precisely, in Hellenistic times. For centuries past, Aramaic had competed with Akkadian as the major language for social interaction and administration. In everyday life, the Aramaic alphabetic script was used increasingly for documentation in cuneiform. Depending on the region and the socio-political situation, this process of superposition and substitution varied in intensity and speed. However, cuneiform script was more and more restricted to monumental-representative and to scholarly contexts. The process was hastened by the final collapse of the last great empires of the Ancient Near East in the seventh and sixth centuries as well as the Macedonian conquests in the fourth century BCE. It is true that in the big institutions of the southern cities, up until the first century CE, cuneiform continued to be written down. But the loss of the corresponding abilities and thereby the loss of the observations, practices, and items of knowledge laid down in cuneiform was an imminent threat. Though expertise in cuneiform shows up even in Late Antiquity, the latest cuneiform texts known today date to the end of the first century CE. The fading of the cuneiform script marks the end of a long-lasting process, which was most probably triggered by the creation of alphabetic systems in the eighteenth century BCE and accelerated by socio-political developments in the following centuries.

But there was at least one interesting attempt at a transfer of the cuneiform materials into a different writing system in order to maintain access to certain aspects of the cuneiform tradition. The so-called Graeco-Babylonica are a case in point.[28] They are documents that transcribe texts from the Sumerian and Akkadian tradition in Greek letters, that is, a *phonetic* transcription of the ancient cuneiform languages to the young Greek alphabet. The texts exhibit a relatively strict consensus on how to "transcribe" the phonetic record of Sumerian and Akkadian. In a certain sense the procedure enlarged the well-known tradition of textual biliteralism—giving a more or less convincing translation of a given (generally Sumerian) text to Akkadian—with the practice of indicating the pronunciation of signs. In this case, the transfer is not only from language into writing, but from an already "written" language, with a decisive emphasis on phonetics. What could be the aim of such an attempt if not that of overcoming the hermetic tradition of the cuneiform culture and the clusters of knowledge that were embedded within it.

Writing is closely associated with the term *text,* referring to both the outer format as such, as well as to the inner structure, the fabric, the tissue of words and meanings. But textuality and the use of writing do not principally coincide as they pertain to different descriptive systems (Ehlich 2007). *De facto* Egypt as well

[28] See (Geller 1997; Westenholz 2007).

as Mesopotamia point to a multimedial textual concept, thus allowing for "texts" even in the earliest phases of writing (Morenz 2007). Protocuneiform and archaic cuneiform documents represent in fact *virtually open texts* in condensed clusters of information (Selz 2007). These "texts" are principally open with respect to the language used for their interpretation: verbalizing, paraphrasing, extending, and unfolding the given information. Several external factors may influence a "text." There is, for instance, the question of genre, which heavily determines a text: a mythological narrative will exhibit specific features not found in a legal document. But not only the normative impact of written genre has been considered, the role of non-written traditions and their impact on written tradition in pre-modern literate societies has seen much debate.[29] On the other hand the fixation of speech and speech-bound texts in writing generates new and different cognitive potentials, especially if literacy is not only bound to the *communicative memory* of a society, but also relates to its *cultural memory*.[30] The two expressions have lately been used with reference to ancient societies, denoting the societal interest of either transferring information within society (*communicative memory*) or keeping information available (*cultural memory*). Writing pertains to both concepts, as it links the aspect of communication to both the storage and performance of information.

5.4 Literacy and the Material Aspects of Writing

From what has been said, the impression may arise that writing is an autodynamic force, being at the same time a vehicle and a motor for the globalization of knowledge. This is certainly not the case. Some of the limiting factors connected to the spread of information via writing have been hinted at above. In a certain sense writing stands in opposition to the globalization of knowledge insofar as it is a technique that requires a high degree of specialization in practices that are localized in both space and time. In societies with restricted literacy, and even more so in premodern societies, this is the dominant pattern!

Another perspective, too rarely adopted, has been recently highlighted by K. Lamberg-Karlowsky. Our attitude toward the role of writing is heavily biased by the particular nature of our evidence, the textual record itself being its main object of study and source of knowing. But it should be kept in mind that, although evidence seems to suggest a high degree of acceptance for cuneiform script (and its derivatives) many peoples did in fact renounce such a take-over. This especially holds true for the initial phase of literacy in the Ancient Near East:

> With the exception of a single region [...] every settlement 'colonized' by the literate i.e. during the so-called Uruk-expansion refused to adopt the written tablet as a communicative device. [...] All indigenous communities exposed to literacy, whether the Proto-Elamite culture on the

[29] See (Wilcke 2000; Macdonald 2005).
[30] See (Assmann 1992; Raible 1999).

> Iranian Plateau, the Uruk in northern Mesopotamia and Anatolia, or the Egyptian in the Levant, refused to assimilate and adopt the written sign as a communication device. It is perhaps difficult for us to accept that writing, a technology which we highly prize, would be self-consciously avoided. Perhaps this is why shelves of books discuss the origin, function, and nature of writing, while the apparent avoidance of becoming literate is all but ignored. (Lamberg-Karlovsky 2003, 63)

Although it may seem to be a quite difficult undertaking to estimate the degree of literacy in Ancient Near Eastern societies, some general observations may be drawn from the available evidence-differing from time to time and from region to region. Thus it can be shown that one has to account not only for a generally restricted number of *literati*, but also within this group differing types and degrees of functional literacy.[31] Full comprehension of the writing system and its capabilities was limited, for the most part, to very few members of an intellectual elite. This mode of restricted literacy, that is, only a small group was able to handle the technology competently in all its details, underscores the important role of writing as a part of *Herrschaftswissen* (Pongratz-Leisten 1999). Nevertheless, even before the invention of the alphabetic mode, simplified but fully functional syllabaries allowed a much broader usage of writing. So, for instance, Old Assyrian cuneiform script (used during the nineteenth and eighteenth centuries BCE in Northern Mesopotamia and Anatolia in a primarily economic (long-distance trade) context) attests to a highly efficient variant of syllabic cuneiform: less than 100 signs were sufficient to encode speech adequately. But interestingly enough this system was not continued even though it could have been easily transferred. It is not clear whether the political situation or, for instance, ideological (prestige) motives, or even the sheer resistance of more complex, existing cuneiform writing traditions, can be held responsible for this situation. A similar case can be observed in the Early Iron Age Aegean (Sherrat 2003).

Literacy then is not a constantly growing feature of Ancient Near Eastern civilizations and thus cannot be seen as a factor enabling or even fostering the process of the globalization of knowledge. On the contrary, the level of the use of writing varies on all scales, from the micro-level of individuals to the macro-level of entire societies. The oscillation between varying degrees of literacy is well known from other historical periods, but the closest parallels to the Ancient Near Eastern situations are offered by medieval Europe. From the eleventh century onwards, for example, a close connection between new approaches to doing business and literacy can be observed: the growth of literacy is a consequence of the production and retention of records, as well as an increasingly dense network of referential uses of written record (Clanchy 1979).

But what about the consequences of a given implementation of script-based communication within a society, which to a large extent bases its system mainly

[31] For a systematic approach, see (Wilcke 2000).

on forms of oral communication? How does such a *scriptural turn* influence the authority of the spoken word?[32]

> The transition from language as sound to writing as symbol is the same as the transition from voice to text and from chief to king. There is a relationship between authorship and authority. Writing is the isolating symbol of power. It isolates the literate and the powerful from those who are illiterate. In virtually every case in which writing is invented, it is not the author but the institutional context of authorship that yields the power. Initially, wherever one finds writing, the author is anonymous – a tool of administrative power directed by a central authority. (Lamberg-Karlovsky 2003, 64–65)

Being a tool as well as a sign of power and authority, writing must—especially in premodern societies—maintain itself in opposition to competing modes of representation, transmission, authority, and so forth. It has to continually prove its societal value. Some intriguing insights concerning the economic side of the implementation of writing in a society can be gained by means of a simple modification of the central theme of Coulmas' book on *Language and Economy* (Coulmas 1992): by substituting the word *language* with *writing* the following complexes result:

1. "Writing is an Asset": Writing and Money in the Development of National Economics (chap. 2)
2. The Value of Writing: Factors of an Economic Profile of Writing (chap. 3)
3. Writing-related Expenditures of Government and Business (chap. 4)
4. Writing Careers: Economic Determinants of Writing Evolution (chap. 5)
5. Economy in Writing: Economic Aspects of the Writing System (chap. 6)
6. Writing Adaption: Differentiation and Integration (chap. 7)

It becomes immediately clear that the entanglement of economic interests and the role of writing are to be considered as important a factor as the globalization of knowledge, not only with regard to modern periods, but also to premodern times! Although these perspectives cannot be elaborated within this paper, I should like to point at least here to the institutional *as well as* to the institutionalized character of early writing, which not only has its bearing on obvious aspects such as the standardization of the system, but also on the content and extension of the knowledge encoded therein: the training of scribes becomes central to the formation and tradition of culturally relevant bodies of knowledge. However, at the same time, the fields of scribal engagement were thus shaped, controlled, and determined. Within their curriculum, exercises and examples not only taught the conventions of writing and of script, but also aided the formation of spheres of knowledge. These

[32]The role of "materiality" with regard to early textual culture as Ancient Near Eastern societies still remains to be investigated. But the range of possible implications is illustrated, for instance, in (Gumbrecht and Pfeiffer 1988).

included operational knowledge as laid out in technical literature, recipes, and administrative documents, accumulated knowledge deriving from observation, lists, tables, productive-speculative knowledge, as in, for example, theology, astronomy, or divination, and representative knowledge, as encoded in literature or royal inscriptions. Although the wealth of written documents extant from the historical phases of Ancient Near Eastern civilizations is indeed impressive, two features must be kept in mind: (1) the use of writing was restricted and the documents are not at all representative of the diversity of cultures and societies which were part of contemporaneous history—and thus of the many levels and fields of knowledge active at that time (2) the documentation itself is characterized by a certain anonymity as regards the fields of knowledge, learning, science, and lore. Certainly, names of "authors" and of individual scholars are known (mainly from first millennium contexts), some of them can be followed over several generations, and networks of experts can be reconstructed especially in late periods in certain fields as astronomy, divination, and medicine. Thus some "careers" of scribes and scholars are nicely documented via the royal correspondence: the king requests their expertise or discusses particular problems with them. But on the whole—and this is a typical feature of the Ancient Near East—the individual scholar and expert is seen (and sees himself) as part of a general tradition; his contribution to the field may be acknowledged, if at all, in the so-called colophons. These "scribal" comments are to be found at the end of cuneiform tablets of mostly canonical texts, stating the "scribe's" name, family, age, and the circumstances of the edition presented.[33]

The establishment of writing as a tool of documentation has had another direct impact on the overall organization of societies' knowledge. The tablets written had to be stored and methods found for the systematic organization of the written record. Management of the written record was an essential activity within the sphere of administration (private or institutional) as well as within the sphere of "literature" (of all sorts). Yet the managing of records affects primarily two levels within the system: the level of textual organization and supplementary information given on the tablets, such as the above-mentioned colophons, but also the numeration of tablets within a series, dating, or giving the document particular external formats and features. These help to differentiate at first glance most of the written documents. Much more difficult is the organization of complete files or dossiers. According to the affiliation of the documents, whether private households, palaces, or temples, the function of archive or library was assigned to a single room, part of a room, or several rooms. We do know that economic and juridical documents were kept in baskets, pots (sometimes with name and/or dating), boxes, and other containers. Larger institutions and libraries stored tablets on shelves and in small niches. Sizes vary within time and context.[34] Although the Library of Alexandria figures as one of the most prominent libraries in the Ancient world and is often mentioned as the "prototype" for collectively stored knowledge,

[33] A representative collection and overview is given in (Hunger 1968).
[34] See (Veenhof 1986; Pedersén 1998).

it must not be forgotten that the Ancient Near East attests to the existence of similar, but much older institutions. Not many of them have been recovered, but certainly the great "library of Assurbanipal," the thousands of texts found in the residential area in Nineveh, or the libraries at Sippar, Nippur, or Babylon were of comparable size and importance. The organization of these huge amounts of materialized knowledge of all kinds, the conditions of accessibility and participation, the systematization of collecting and excluding texts for these institutions has not yet been extensively studied. But these materials should certainly be taken into account when analyzing the role of writing and the globalization of knowledge.

The use of writing enables the logical disciplining of thought (Stetter 1990, 279). This at first glance somewhat banal observation is easily understandable with regard to the level of content. But of no less importance is the impact of the materiality of writing on the generation of new knowledge as well as on the reorganization and redirection of existing fields. It is the scriptural mediation of thought that is inevitably linked to the external format as well as to the internal organization of a writing system. Spatiality is a particular characteristic of writing (whereas language is not spatial, but at best linear!) thus extending the possibilities of the latter. The formal criteria, the aesthetic profile of a text, the metapragmatics of writing[35] is a domain of knowledge in its own right, transferred within the practice of writing. Its effects can be observed not only in the development of previously unknown formats such as tables, which allow for a two-dimensional presentation of information. But also the subtle technical changes such as the shifting ergonomics of writing itself are to be taken into consideration. The morph (form), the external features of a writing system, to a certain extent directly condition its applicability, for example, with regards to the velocity of writing and reading. These relate, for example, to the possibility of multiplying texts, thus producing multiple sets of one and the same record, or making text easily available. Even the development of cursive writing styles follows from the ever increasing necessity of writing huge amounts of texts, which do not serve monumental or ceremonial purposes. Rationalization of the process of writing is often shaped by the demands of speech-related writing. On the other hand the graphic organization of written text relates to its perception. So, for instance, writing in scriptura *continua* is not only difficult for modern readers, but testifies to the tradition of reading as an oral activity (Saenger 1994). The relation between language and writing may, according to the respective system, necessitate the conveyance of secondary information, for instance, modes, stress, intonation, even the indication of word boundaries, the end of phrases, and so forth. Thus many writing systems develop diagrammatical elements to render phenomena, which are not or cannot be represented on the sign-level (graphematic) itself, such as spatial distribution to mark word-boundaries, punctuation, to mark the end of phrases or the mode of speech (exclamation! request? citation ""), or segmentation of paragraphs to mark

[35] The term is prominent in anthropological linguistics, but not in grammatology, see (Silverstein 1993).

contextual boundaries (Raible 1991a); these translate semantic macrostructures of texts, as well as microstructures of a spoken situation (Frank 1993).

Besides operational knowledge transported by word of mouth or directly (and indirectly) learned by concrete observation, with the invention of writing a new quality of exchange arises. Stored in writing, the archives and libraries of the central places outside of Mesopotamia, such as Boghazkoy/Hattusas in Anatolia, Ras Shamra/Ugarit on the western periphery, and Tell al-Amarna in Egypt, give an impression of what the "exported" assemblages of knowledge contained (Pedersén 1998). As these texts—or at least some of them—were part of the curricula they represent bodies of knowledge and modes of thinking and organizing knowledge. As such they are not only subject to vertical diachronic transmission within a given society, but are also part of the horizontal (synchronic and diachronic) transmission into foreign cultural contexts.

Within the long-lasting process of the *globalization of knowledge* writing as a dynamic, yet at the same time systematically controlled *Kulturtechnik*, manifests its consequences of different levels. Generalizing the evidence gained from the situation in the Ancient Near East, the following spheres of interrelation make the role of writing evident:

1. as a media for the exchange, transfer, and storage of all sorts of knowledge
2. as a dimensional extension of cognitive facilities
3. as a shaper of thought, stimulating paths of reflection and articulation
4. as giving/limiting/excluding access to certain domains of knowledge
5. as affecting and transforming societies as a whole.

On different scales and within differing contexts they are concerned with the transmission of knowledge of any kind, whether intuitive knowledge or practitioners' knowledge, symbolically represented knowledge, technological or scientific knowledge, or second- and higher-order knowledge.

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Chapter 6
The Origins of Writing and Arithmetic

Peter Damerow

6.1 Globalized Systems of Writing and Arithmetic

Writing and arithmetic are cultural techniques which are essential conditions of the organization of modern societies. They are usually considered as distinct human activities with distinct origins. However, recent work based on archaeological evidence suggests a common origin.[1] It is a basic claim of the present paper that there were close relations between writing and arithmetic at the time of their emergence.

Both writing and arithmetic are based on operations with systems of symbols that represent *cognitive constructions*, either directly or indirectly.[2] The main reason for considering writing and arithmetic to be relatively independent of each other is that the cognitive constructions they represent and the way in which they represent them are different.

Developed writing systems are predominantly glottographic. They represent language by some kind of phonetic coding.[3] Such writing systems are based on a

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[1]The analysis of the origins of writing and arithmetic presented here focuses on the development and application of the cuneiform writing system in the ancient Near East. Due to the durability of clay tablets used as writing material, the excavated tablets and other artifacts from this region provide an abundance of information, revealing the development from the precursors of writing and arithmetic in the fourth millennium BCE to the spreading of the technology of writing throughout the Mediterranean area,see (Sasson 1995, vol. 4), and the creation of Babylonian mathematics, see (Robson 2008).

[2]The term *cognitive construction* is used here in the widest sense, and includes all forms of the mental organization of feelings, perceptions, beliefs and thoughts. Such mental constructions are usually organized in cognitive structures consisting of objects represented by mental images or conceptual structures together with mental operations related to them, systems which may be called *mental models*, see (Renn and Damerow 2007) and also the introduction to this volume (chapter 1). Mental constructions and models can be externally represented by symbols and symbol systems. The relation between mental constructions and external symbols may be called *iconic* if the symbol somehow depicts a mental image, or *conventional* if the symbol represents a mental construction only by arbitrary definition. Writing and arithmetic are both tools for the external symbolic representation of mental constructions and models. They both use primarily conventionally defined symbol systems.

[3]We follow Hyman (2006), who offers a conceptual clarification of the various types of relations between written texts and their meaning, with specific focus on the development of early writing systems. Glottographic representation of meaning is based on the phonetic coding of language. It is closely linked to reading since the representation determines the chain of utterances of words.

Figure 6.1: Obverse, edge and reverse of an archaic Babylonian bookkeeping record (ca. 3200-3000 BCE).

standardized and stable inventory of graphemes representing words, morphemes, syllables or phonemes. This inventory has to be historically transmitted by a social group and to be rich enough to represent an essential part of the language spoken by this group. According to this definition, cognitive constructions are represented by writing only indirectly, insofar as they are expressed in language.

By contrast, arithmetical systems are non-glottographic, representing cognitive constructions such as numbers and numerical operations directly.[4] They are based on a standardized and stable inventory including graphemes designating quantities and rules for performing arithmetical operations. This inventory has to be historically transmitted by a social group and be rich enough to perform basic calculations comprising additions and multiplications.[5]

By contrast, a non-glottographic representation of meaning is closely related to verbalizing. In this case, symbols or chains of symbols determine iconically or conventionally their meaning without determining how this meaning has to be verbalized.

[4]For a systematic, theoretical reconstruction of the development of knowledge representation structures reflecting arithmetical operations, see (Damerow 2007).

[5]The non-glottographic representation of cognitive constructions constituting arithmetic does not exclude any significant role language may play for building these up and transmitting them between members of a social group. Language may serve as a means to make the rules of numerical operations explicit. Language may also serve as a means to conceptualize and communicate the cognitive context of such rules, in particular, systems of numbers. As far as the relation

Numerous systems of writing and of arithmetic developed in history and spread geographically until they reached the level of globalization characteristic of modern societies.[6] Given the great variety of different systems of writing and arithmetic, this globalization process was anything but a simple process of diffusion. Throughout the world, local developments of writing and arithmetic have interacted with each other in various ways. In the case of arithmetic, the final outcome is a relatively unified system of arithmetical notation and calculation methods. In the case of writing, the situation is different. Today, as a result of globalization processes, writing is used all over the world, but neither the languages nor the writing systems have been unified by these processes.[7]

The globalization processes of writing and arithmetic, which resulted in the present situation, are far from being adequately investigated or well understood. Neither in the case of writing nor of arithmetic is it clear to what extent globalization is the result of transfer and diffusion of knowledge from one place of origin to other regions of the world, and to what extent it is the result of independent developments that interacted with each other and merged into current systems of writing and arithmetic.

6.2 When is Writing Writing and When Is Arithmetic Arithmetic?

To investigate the early phases of the emergence, development, transfer, diffusion and, finally, globalization of writing and arithmetic, the different types of knowledge that evolved over the course of this process need to be identified. Writing and arithmetic have been characterized above as knowledge representation structures that are shared and historically transmitted by certain social groups or populations. They are external representations of mental constructions that over the course of their development, as will become clear in the following, became increasingly different and independent of each other. What they do have in common is that the media of these representations are constituted by conventionally defined symbol systems.

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of symbolic representation and language is concerned, arithmetic is thus in a certain sense the opposite of writing. Writing refers to cognitive constructions by operations within a symbolic system that represents language by phonetic coding. Arithmetic refers to cognitive constructions by operations within a symbolic system, which represent these cognitive constructions themselves by arithmetical symbols and symbolic operations, while language is used only to conceptualize and verbalize these operations.

[6] Writing systems and arithmetical systems both exist in different forms using different means of symbolic representation. Different languages may be represented by different writing systems, or by the same writing system with the same or with partly different phonetic coding. Correspondingly, different arithmetical systems may be represented by the same or by different systems of symbolic notation. Even the same arithmetical system may be represented quite differently in different contexts.

[7] A further step in the process of globalization, however, may create in a multilingual context a so-called "lingua franca." In certain areas of application, such as the field of modern sciences, the English language in combination with Latin characters developed into a kind of written lingua franca, facilitating the scientific documentation and communication of scientific knowledge.

Of course, this common basis of writing and arithmetic is not specific to such symbol systems. Their use, transmitted by rituals or instruction, goes back some 10,000 to 40,000 years to the Upper Paleolithic Revolution, that is, to a prehistoric period of mankind, long before the occurrence of a technology that can be interpreted as writing or arithmetic as we know it.[8] In order to understand how writing and arithmetic emerged, we must study the specific kinds of symbolic representation that actually contributed to their simultaneous emergence in the Early Bronze Age.[9]

Which specific characteristics of those kinds of symbolic representation demarcate the onset of the development of writing and arithmetic? Any investigation of the early development of writing and arithmetic faces a problem: the cognitive constructions they represent were constituted by historically changing sets of mental operations with varying areas of application. Even if a certain symbolic representation depicts the same object or setting over a long time, its meaning may have altered substantially according to the changing cognitive constructions that determine its symbolic meaning, on the one hand, and to which the object or setting is mentally assimilated, on the other. The investigation of the origins of writing and arithmetic therefore requires some conceptual clarification of the specific kinds of cognitive constructions that formed the basis for the emergence of writing and arithmetic.

Writing: From a modern point of view, it makes sense to define writing as a glottographic representation of spoken language by phonetic coding in a lasting medium. This definition makes sense in a globalized context in which writing is essentially a universally applied means to represent and communicate all forms of knowledge. Given that this function of writing is in fact the major characteristic of its modern use, it is an abstraction from its numerous other functions,[10] in particular from its various functions in different ranges of application, and in different cognitive contexts. However, at the early stages of its development, writing co-developed with certain areas of the social reality of the time, such as economical redistribution, multilingualism, foreign trade, religious rituals or the training of officials. It is precisely the development of the relation between the changing ranges of application to real objects and the changing knowledge about them that accounts for the great variety of the early developing writing systems. The modern definition is indifferent to such conditions. Thus, it comes as no surprise that the kinds of geographically and historically changing representations of language in the early phases of the development of writing that may be considered as writing in the modern sense are a controversial issue.[11]

[8] For a detailed study of the early use of symbols, see (Leroi-Gourhan 1993).

[9] See (Damerow 1998) for a reconstruction of the cognitive processes involved in the prehistoric development of symbolic representation.

[10] For the variety of different functions of writing, see chapter 5.

[11] In the sequel to the influential study of Gelb (1952), several attempts have been made to classify the various kinds of symbolic representation involved in the early development of writing, and that left traces distinguishing writing systems based on Latin characters from other writing systems

Arithmetic: The situation is similar in the case of arithmetic. From a modern point of view, arithmetic can be defined as a non-glottographic representation of numbers and numerical operations by symbols and symbol transformation rules. Again, this definition makes sense in a globalized context in which arithmetic is essentially a universally applied means of representing and communicating the handling of counted or measured quantities of arbitrary objects. The definition refers to an abstract concept of number. It does not distinguish between different ranges of application and different cognitive contexts. At the early stages of its development, however, arithmetic also co-developed with certain areas of the social reality of the time, such as the accumulation, trading and redistribution of commodities in stratified societies, the training of administrators or the institutionalization of early scholarship, such as Babylonian astronomy, Platonic philosophy or Euclidean mathematics. It is the development of techniques for handling quantities and for reflecting on and symbolizing the operations with them that accounts for the great variety of the early developing systems of numerical operations, some of which survived among recent indigenous cultures comparable to those of the Stone Age. Before they had contact with the modern world, the tribes of Australia and South America did not count beyond three. Other indigenous cultures used extended counting techniques, such as the body counting of the natives of New Guinea, and sometimes also used tallies to control quantities. But the areas in which these techniques were applied were narrowly restricted. Moreover, these techniques did not necessarily include numerical operations, such as additions and multiplications, which today are associated with any number concept.[12] Since the modern definition of arithmetic is heavily influenced by the Platonic and Kantian tradition, according to which the number concept is an a priori concept, not resulting from experience, it is not affected by the historically and geographically changing cognitive constructions on which numerical operations were based. Thus, this definition does not enable a decision about which early arithmetical techniques indicate knowledge about numbers in the modern sense.

In view of these ambiguities concerning the common concepts of writing and arithmetic, we will distinguish here systematically between proto-writing and writing, and also between proto-arithmetic and arithmetic. The term *proto-writing* will

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such as Chinese, Hebrew or Arabic; see, for example, the second chapter of (DeFrancis 1989, 20–64). From his taxonomy, Gelb speculatively derived a universal sequence of the development from non-glottographic symbols to glottographic writing, which led him to erroneous claims such as that the then still undeciphered writing system of the Maya could not be based on phonetic coding (Gelb 1952, 54–59), a claim that, after the successful decipherment of the Mayan writing system, turned out to be fallacious. While the classification of writing systems and their constituents provides helpful tools for the description of the differences between them, such a classification in itself contributes little to the understanding of the historical processes that determined their emergence, development and globalization. For a thorough critique of the interpretation of typological ideals as an evolutionary stage, see (Michalowski 1994).

[12] For a theoretical reconstruction of the cognitive background of such techniques, see the classical study of Wertheimer (1925) and the extended analysis of Damerow (1996, in particular chapter 9).

be used to designate the *non-glottographic* symbol systems that historically precede writing and share some functions with the writing system they precede, but that could not have been used to represent, independent of context, the flow of free speech.[13] The term *proto-arithmetic* will be used to designate symbol systems, such as tallies or units of counting, for controlling quantities in direct relationship with the objects and symbols that represent these objects. Such systems of symbols do not represent any kind of context-independent numbers reflecting accumulated experiences achieved in the process of controlling quantities by means of correspondences. Their invention and use may have resulted in the development of arithmetical techniques, but they can be used for controlling quantities of objects, even without any cognitive numerical construct.

6.3 The Emergence of Proto-Cuneiform Bookkeeping in the Ancient Near East

The following analysis of the origins of writing and arithmetic will focus on the development of cuneiform writing in Mesopotamia. There are two reasons to analyze specifically the early development of the cuneiform writing system.

First, cuneiform writing, as far as we know, is the earliest writing system in the world.[14] During the roughly 3,000 years of its use, it spread to many regions of the Near East and moreover influenced directly or indirectly the development of numerous other writing systems used in the Mediterranean area and the Western part of the Eurasian continent.

Second, due to the durability of clay as a writing medium, the early history of the cuneiform writing system and its possible precursors are documented by an abundance of archaeological findings. Moreover, a long tradition of archaeological and philological research contributes to the existing knowledge in this field of scholarly study, so that the answers to many questions are not dependent on more or less risky speculations on historical opportunities and possibilities.

Two major kinds of symbolic representation used in Mesopotamia and in neighboring regions have been considered as immediate precursors of writing. One is the use of *seal impressions* on the stoppers of storage jars, door locks and other means of securing property. They indicate ownership by symbolically representing the owner, or ensure some kind of legal binding by symbolically representing the person or institution that controls, through influence or power, the adherence to the social behavior signified by the seal impression. Such seal impressions were produced by stamp and cylinder seals. They were invented in the fourth millennium BCE in Mesopotamia, and later adopted in Egypt and by the Indus civilization.

[13] It should be noted that this definition does not exclude that phonetic coding was used for specific purposes.

[14] This is obviously true for the early writing systems of China and Meso-America, which were created independently, but developed or at least attested only much later. The situation is less clear in the case of Egyptian hieroglyphs. See the discussion of the earliest attestations of Egyptian writing by John Baines in (Houston 2004).

The representation is partly iconic, depicting persons, objects, mythological figures or complex scenes, but it seems obvious that their main reference to the social setting in which they were used was conventionally determined by the activities and transactions with regard to which they functioned.[15]

The other kind of symbolic representation that contributed directly to the invention of writing is a certain use of small, geometrically shaped tokens made from clay. Thousands of such tokens have been found at archaeological sites scattered over the regions of the Near East. The function of these tokens remained obscure until their connection to the origins of cuneiform writing was discovered. This connection is still the subject of controversial debate.[16] There is, however, a basic agreement that at least in the second half of the fourth millennium BCE, such tokens were used as counters, that is, they were used in direct relationship with objects or units of measurement.

Some of the tokens look like icons of the objects they may have represented. They are shaped like small models of these objects (animals, containers, and so forth). The shapes of some of them resemble signs of the later script, suggesting that they had a function similar to that of logograms of early writing systems. Most of the tokens, however, are completely abstract (spheres, cylinders, cones, tetrahedrons, lenses, discs, pellets). Their relation to the objects they may have represented must have been determined merely by conventions concerning their use in certain contexts. In the second half of the fourth millennium BCE, combinations of equal or partially different tokens were occasionally included in closed and sealed hollow clay balls, securing as bullae the information represented by these combinations. While such closed assemblages would obviously represent significant indicators of the ultimate arithmetic meaning of early clay markers, the evidence from opened or scanned clay balls is so meager as to be discountable. Thus, tokens shaped like models of objects have not been demonstrated to have been included among such assemblages; nor can we state with any confidence whether counts of simple tokens within clay balls exceeded some number representing bundling units in the proto-cuneiform records (generally either six or ten, dependent on the numerical system involved); and finally, combinations of differently shaped tokens in the balls do not show regularities that would indicate the representation of standardized numerical systems.[17]

Nevertheless, there can be no doubt that the tokens were actually used as counters. The strongest indication for this use is provided by marks that were sometimes impressed into the moist clay surfaces of the bullae using a stylus, fingers, or the tokens themselves. With few exceptions, such impressions correspond precisely to the tokens inside; they map combinations of impressions to combi-

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[15]See the interesting attempt to reconstruct the hierarchy of the administration of Susa before the invention of writing from the application of sealings and their motifs by Dittmann (1986).

[16]For an extensive documentation of such tokens, see (Schmandt-Besserat 1992). Her classifications of these tokens, the attribution to specific archaeological layers and thus her datings, as well as her speculative interpretation of their functions, however, have met with severe criticism.

[17]See (Bauer et al. 1998, 46–56; Englund 2006; Damerow and Englund forthcoming).

nations of counters. Furthermore, the arrangements of such impressions resemble numerical notations in the later script. Summing up these findings, the tokens were used as counters, but cuneiform lacks the essential attributes of abstract numbers. They were used as proto-arithmetical tools in the sense defined above.

The archaeological findings show another innovation which occurred around the same time as the sealed bullae: small sealed clay tablets bearing combinations of marks similar to those sometimes impressed into the surface of bullae. These so-called *numerical tablets* share with the counters the lack of indications for standardized numerical systems. These so-called numerical tablets seem to share with the counters an ambivalence to the standardization of numerical systems. For instance, numerical signs were repeated more than nine times in some documents from Jebel Aruda. This indicates that in those documents the signs may still have represented the real objects or containers, although these sign clusters were themselves embedded in strings of numerical signs, suggesting the full notations reflected an advanced system of numerical bundling (Bauer et al. 1998, 50–51 and 214).

Around the end of the fourth millennium BCE, another innovation was introduced which was key to the development of writing and arithmetic. Clay tablets found in Uruk in southern Mesopotamia, in Susa in the region of Khūzestān, and (one example) in Godin Tepe in the Zagros mountains of Iran, as well as a seal impression and a numerical notation, display one or two graphemes drawn with a stylus onto the moist clay. These graphemes on *numero-ideographic tablets* indicated the object, the quantity of which was registered by the numerical notation.

The invention of graphemes complementing seal impressions and numerical notations offered virtually unlimited opportunities for representing structured information. It was much easier to invent a new grapheme than to carve a new seal. Furthermore, by using graphemes and dividing the tablets into different fields, more information could be placed on one tablet than was previously possible. These opportunities were soon used extensively. Hundreds of different graphemes were invented. These were standardized, at least partly, to represent objects, persons, institutions, types of transactions, and so forth. The tablets were divided by lines into hierarchically ordered fields, each one containing a specific entry providing information about some economic activity. The nearly 5,000 extant tablets and fragments of such *proto-cuneiform adminstrative texts* represent the earliest form and, at the same time, a transient stage of the development of both cuneiform writing and Babylonian arithmetic.

6.4 The Inherited Semantics of Proto-Cuneiform Administrative Tablets

Proto-cuneiform writing inherited from its preliterate precursors its area of application as an administrative tool and its functions within the context of administrative control. The preliterate administrative tools (seal impressions, counters, stylus impressions representing counters) were used to control activities such as various kinds of transfer of economical resources and products. In order to control these activities, information had to be available about the four types of conditions that determined an activity of this kind: the kind of resource or product involved; the amount of this resource or product; the agent concerned by the activity; and the official or office in the administration responsible for controlling the activity. Precisely these four conditions are the main semantic categories of proto-cuneiform administrative tablets.

The administrators using the preliterate precursors or these tablets (numerical tablets with seal impressions and numerical notations) to record such conditions were unable to document them in a way that the resulting documents could be interpreted independently of the context. In order to interpret, for instance, a numerical tablet or sealed bullae with counters, and to derive the specific information about who authorized what with these documents, a number of conditions have to be known: the owner of the seal; the kind of activity he was responsible for; the type of product related to the specific activity; the procedure of counting or measuring the amount of the product applied in this case; and the function of the document.

The numero-ideographic tablets made one of these implicit categories of information explicit by introducing graphemes for the objects of the documented activities, thus paving the way for the invention of proto-cuneiform. In the developed proto-cuneiform system, this inherited category was the general semantic class of many graphemes with iconic relations to various resources and products.

This did not lead, however, to a logographic archetype of cuneiform writing, as was often taken for granted (Gelb 1952). The use of graphemes was not generalized from words or morphemes of the Sumerian (or any other) language, but rather from implicit and explicit semantic categories of bookkeeping practices; graphemes did not represent these categories independent of such practices. Proto-cuneiform was developed to improve the functions of its preliterate precursors. This required a greater variety of semantic coding than the simple matching of graphemes with objects. Thus, agents, officials and offices, in particular, were no longer represented predominantly by seal impressions and the context of their use, but by newly created sign combinations.

A statistical analysis has shown that the number of such sign combinations is much higher than the number of uses that could be interpreted as logographic (Damerow and Englund forthcoming). The subject of this analysis was a sample of eighty-six closely related tablets and tablet fragments: the tablets of the former Erlenmeyer collection.[18] The sample tablets contain about 780 entries. The number of different signs and sign combinations of these entries representing products

[18]The collection, preliminarily published in (Nissen et al. 1993) and electronically accessible at the CDLI website, http://cdli.ucla.edu (search for the primary publication *MSVO 3*), turned out to be highly significant for our understanding of the sign combinations representing agents of economical transactions. In 1989 they were auctioned off; the auction at Christie's in London included lots with several artifacts each. The majority of the tablets were purchased by the

is less than thirty, but the number of different sign combinations representing agents concerned with the registered activities is greater than 300.

The significance of this result in revealing the extent to which proto-cuneiform writing represents language patterns becomes evident if we extrapolate the figures to the total corpus of the more than 6,600 proto-cuneiform tablets and tablet fragments. This corpus contains close to 40,000 entries.[19] Assuming that the statistical relations are roughly similar to those in the analyzed group of sample texts, we have to expect more than 23,000 different sign combinations representing agents. If proto-cuneiform sign combinations should, in fact, represent language patterns, these sign combinations representing agents are evidently the candidates for phonetic coding. However, in spite of the fact that in many cases the phonetic values of the corresponding signs of later cuneiform writing are known, the attempts to interpret the sign combinations as phonetically coded Sumerian or Akkadian names, or designations of institutions, failed. After some eighty years of work on the question of the language affiliation of the proto-cuneiform corpus, the debates surrounding it still focus on less than ten examples of alleged phonetic readings.

The emergence of proto-cuneiform brought about innovative new technologies, also with regard to how quantities of resources and products were controlled. The numerical signs of proto-cuneiform tablets are now highly standardized and organized in numerical systems with standardized relations between the different units. Combinations of units were converted into a standardized form by replacing repeated numerical signs by signs with a higher value as soon as the value they represent was reached.

The resulting numerical notations, which often represent hundreds of thousands of units, seem to correspond perfectly to the later tradition of the arithmetic of cuneiform writing. This impression, however, is misleading. The standardized numerical systems inherited the lack of differentiation of quantity and quality from the context-dependent use of their precursors. This resulted in a short-lived transitional system of proto-arithmetic, which is unparalleled by any other numerical system in the world. The basic numerical signs of the proto-cuneiform administrative documents changed their numerical values depending on the quantified objects, or more precisely, on the units of the metrological system of their quantification. The fact that the values of the signs changed so radically that not even the order of their sizes was kept constant considerably reduced the ambiguity resulting from the context-dependency of the numerical notations.

A further characteristic of the numerical notations on the proto-cuneiform tablets evidencing their context-dependency is the smooth transition between numerical and non-numerical proto-cuneiform signs. Numerical signs were partly

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Land Berlin and are now on permanent loan to the Vorderasiatisches Museum; the rest of the collection is distributed among three other museums and some private collectors.

[19] See the contribution by Englund in (Bauer et al. 1998, 65–81).

used also to designate objects, and the incised pictographs of cuneiform writing, if used in the numerical context of an account, could represent numerical values.

According to the dependency of numerical values on individual contexts, there existed no context-independent techniques of performing calculations. *Additions* could be performed with the numerical impressions as they were performed with counters. *Multiplication* did not exist as a generally applicable calculation technique. However, three types of operations can be identified in proto-cuneiform administrative documents, which can be considered as precursors of the multiplication technique.

The *first* type is to reproduce a quantity several times, for instance, to get from an amount of grain for one day the amount for a month of thirty days. From an arithmetical point of view, this operation corresponds to a multiplication with a small natural number. Such an operation could easily be performed by repeated addition.

The *second* type of multiplication depends on a numerical relation between two quantities, such as the rule that for the production of three pieces of a certain grain product, five units of barley were required. By applying the first type of operation equally to both quantities, further values with the same relation could be achieved. From an arithmetical point of view, such calculations correspond to multiplications with a fraction; in the given example the multiplication with five over three, but these factors remained implicit and were never written.

The *third* type of operation corresponding to the later multiplication technique was the most sophisticated one. Accordingly, the results documented by administrative documents contain a remarkably high percentage of errors. This type of operation was used exclusively by surveyors to calculate the areas of fields from measurements of the lengths of their sides, applying to irregular quadrangles what is known from much later history as the surveyor's formula. Arithmetically, this operation corresponds to multiplying the means of opposite sides. Since the system of length measurements and the system of area measurements were not coordinated with each other, the procedure had to be specific for this single purpose and could not be applied to any other type of problem.

Thus, the heritage of preliterate administrative tools determined not only the area of application and the functions of the proto-cuneiform writing system, but moreover the detailed semantics of its sign combinations. The outcome was a historically unique, integrated system of proto-writing and proto-arithmetic in the sense defined above.

6.5 The Emergence of Proto-Cuneiform Bookkeeping as a Transformation Process

The extant proto-cuneiform tablets with their incipient form of writing and arithmetic provide us with a missing link between non-literate and literate societies. They show that the seemingly sudden emergence of writing and arithmetic at the turn of the fourth to the third millennium in Mesopotamia was actually the result of a complex transformation process. On the one hand, the proto-cuneiform system documents the end of a long-lasting historical process of transformation, encompassing several independent dimensions. On the other hand, it represents only the nucleus from which writing and arithmetic emerged.

The roots of both cultural techniques reach back into the Upper Palaeolitic when humans began to represent mental constructs by iconic or abstract symbols. What we know from ethnology about indigenous cultures indicates that, on this basis, the use of tallies in rural communities and probably even the use of limited counting sequences may have been established. However, for some 10,000 years, characterized by the globalization of agricultural, ceramic and metallurgical technologies, no remarkable further developments toward the invention of writing and arithmetic can be identified.

The change that can be observed in the second half of the fourth millennium can be conceived of as a transformation process that was triggered by the establishment of a redistributive economy in the context of the emergence of cities, and the stratification of the society in early state organizations. This transformation process started with an exploitation to their limits of the potentials of existing tools of symbolic representation, followed by a transfer of symbolically represented information to a new medium. Two types of independent information were concerned: the information represented by combinations of counters used to control quantities; and the information represented by seal impressions used to secure the objects of the administration. These types of information were transferred to this common medium by using sealed clay bullae with combinations of tokens inside and, finally, sealed clay tablets with numerical impressions.

The extant simple-shaped clay counters used in rural communities for controlling small quantities of resources and products were differentiated. The increased number of shapes corresponds to the new economical circumstances, which required greater quantities of more objects to be controlled. But the limitations created by such an exploitation of tools for a completely different social setting are obvious. Thus, it comes as no surprise that they soon underwent a transformation process.

The transformation of these tools started with a transfer of two types of independent information to a new common medium. The information represented by combinations of counters used to control quantities and the information represented by seal impressions used to secure the objects of the administration were transferred to this common medium by using clay bullae and, finally, clay tablets. The potential of these clay tablets, in particular, determined the further development toward proto-cuneiform writing. They enabled the represented amount of information to be extended and an increase in the number of semantic categories for different types of information. This new potential was first used by means of the numero-ideographic tablets to indicate the objects of economic transactions. To a greater degree than their preliterate precursors, such tablets became independent of the context in which they were written.

The potential was further realized by three innovations. First, the semantic categories of the newly introduced graphemes were extended so that they could cover all types of information needed for controlling the accumulation and distribution of resources and products. Second, the economic and administrative activities involved were modeled in terms of these categories, and representation structures were created for mapping the modeled activities onto the tablets. Third, the graphemes and formats created in this process of transforming information were standardized, as far as this was possible.

The administrative proto-cuneiform documents representing the majority of the texts of the proto-cuneiform corpus can thus be considered as the transformation of a mental model of the accumulation and distribution of resources and products into an external symbolic representation comprising formats for the major categories of economic information and rules for symbolic operations representing economic and administrative activities. This interpretation of the documents implies—as far as the administrative texts are concerned—that the development toward the proto-cuneiform writing system did not involve any substantial tendency to eliminate the dependency of either the semantic of the numerical notations, or of the additional graphemes on their function to control economical processes. Proto-cuneiform writing thus remained essentially a system of proto-writing, and the calculations performed with the context-dependent numerical notations remained essentially operations in proto-arithmetical systems. Both systems, of course, were incomparably more complex and powerful than their preliterate precursors.

This was not the end of the transformation process, however. The administrators of the early city states of Mesopotamia used proto-cuneiform tools exclusively to control economical transactions, but their potential to represent mental constructions reached far beyond this limited field of application. This implicit potential of proto-cuneiform to be further developed toward writing and arithmetic, however, was first noticeable only as a side effect of its main functions. The great number of graphemes with conventional meanings required some kind of institutional support for transferring the necessary knowledge for their use from one generation to the next. Such training institutions, then as now, do not realize economical goals, but rather teach how to use tools. Thus, we find attempts to generalize proto-cuneiform writing and its inherent techniques of operating with numerical notations specifically in a school context.

6.6 The Unexplored Transition from Proto-Writing and Proto-Arithmetic to Writing and Arithmetic

With regard to this further development, an atypical group of some 670 texts and fragments deserves closer attention. These represent standardized lexical lists (Englund and Nissen 1993) which are generally considered to be school texts. The lists contain entries ordered by semantic similarity. Some of them contain sign combinations related to resources and products such as animals, plants or manufactured products; others contain sign combinations related to geographical locations and persons. One list may even represent some kind of text of an oral rhetoric tradition. If these lexical lists did, in fact, serve to teach signs and sign combinations relevant for the later bookkeeping practice of the disciples, one would expect a high communality with the designations of resources and products that occurred frequently in the proto-cuneiform administrative documents. This, however, in general is not true. Simple sign combinations, which are recorded mainly at the beginning of a list, are often used in administrative texts as well. More complex sign combinations, however, can rarely be found in the corpus of administrative texts. The scribes who designed the lexical lists and probably used them for teaching purposes had a more sophisticated perspective in mind than to simply satisfy the immediate requirements of the administration's practitioners.

A similar tendency to depart from administrative purposes is characteristic of certain texts with calculations, which were obviously written in an educational context. Apart from their formats, which differ from the standard formats of administrative proto-cuneiform tablets, these texts characteristically contain problems that never occurred in practical contexts. One way to construct such problems was to use unrealistic numerical values, for instance, by asking the area of a field to be calculated, giving measurements that were much too large for any real field. Another way, which is attested only in later texts, however, was to reverse the problems of the practitioners. While the surveyors of the administration always measured the lengths and widths of fields and calculated the areas, in such a problem, the area of a field together with its length may be given and the task would be to calculate its width.

Such extensions of the main functions of administrative proto-cuneiform documents may have triggered the development of proto-cuneiform into cuneiform writing, and of proto-arithmetical techniques of calculation without numbers into the arithmetic of Babylonian mathematics. It is also possible, however, that specific achievements in the context of teaching and learning played only a minor role in the development toward writing and arithmetic. There were at least several other factors that may have initiated this development. The conditions which determined, in Mesopotamia in particular and in the wider area of neighboring regions in general, the further development of writing and arithmetic were, in fact, different from and much more complex than those that induced and constrained the creation of proto-cuneiform.

1. The proliferation of persons, institutions and locations to be identified made it increasingly necessary to find a coding principle (phonetization) according to which the symbolic coding and decoding of names could be simplified. (Charvát 2002)

2. The areas of application in which writing was used were extended from the documentation of economical activities, first to the support of memorizing orally transmitted texts such as hymns, incantations, proverbs and epic poems, later also to formalized texts with variable content, such as contracts and legal documents, and, finally, to freely composed texts such as letters.

3. The development in the third millennium BCE from the city states of the Early Dynastic Period (Ur, Shuruppak, Girsu, and so forth) to empires, which at times covered great parts of Mesopotamia (Sargonic empire, Ur III state), consequently had growing bureaucracies which brought about the specialization of scribal professions and the introduction of specialized terminologies and mathematical techniques used, in particular, in administrative units.

4. Proto-cuneiform was developed into cuneiform writing in a multilingual setting in which, in particular, Sumerian, a language with unknown provenance, and the semitic language Akkadian coexisted with alternating dominance.

5. Proto-cuneiform was not the only writing system to emerge at the end of the fourth millennium BCE. Two other writing systems were created which were related in different ways to proto-cuneiform: the proto-Elamite writing system of the highlands of Iran[20] and the system of Egyptian hieroglyphs together with its hieratic form.[21]

6. From the end of the third millennium and throughout the second millennium, cuneiform writing systems were created in the Levantine and Anatolian regions to the west and north west of Mesopotamia for several languages (Hurrian, Hittite, Hattic, Palaic, Luwian, Ugaritic). At the same time, to the east of Mesopotamia, cuneiform Elamite was created and used throughout the area until the second half of the first millennium when it was complemented by Old Persian cuneiform.

7. Around the same time, some completely different writing systems began to emerge and later disappeared again, partly in some of the regions to the north and to the east of Mesopotamia (Anatolian hieroglyphs, linear Elamite, Indus script), partly further west in the Mediterranean region, in particular on the islands of Cyprus and Crete (Cretan hieroglyphs, Linear A, Linear B, Cypro-Minoan syllabary). Furthermore, in the mid-second millennium in the Levantine region, the first alphabetic systems emerged (Proto-Sinaitic, Proto-Canaanite) followed by the Phoenician alphabet at the end of the millennium. Finally, the widespread alphabetic writing systems of the Arabic and the Greco-Roman world were created. These have survived until the present day.

[20]See Englund in (Houston 2004, 100–149; Dahl 2005).
[21]See Baines in (Houston 2004, 150–189; Wengrow 2006).

This brief survey of the conditions that induced and constrained the development of writing and arithmetic shows that the development of the various systems of writing and calculation cannot have followed a common pattern, but must have been different under different social, geographical and historical conditions. The development of writing and arithmetic depended on the interaction of different processes, such as:

1. the phonetization of a system of proto-writing, at the beginning allegedly (in the case of proto-cuneiform) by using the rebus principle, followed by the creation of standardized syllabaries or alphabets,

2. the generalization of the areas of application of a writing system, followed by a differentiation into segments, often with different lexicons, partly even with different syntax and different ways of constructing semantic relations as, for instance, in the case of the differentiation of writing and mathematics,

3. the adaptation of a writing system to a language other than the one it was created for,

4. the dissemination of writing and arithmetic by trade or by the migration of people,

5. the development of writing and arithmetic stimulated by the influence of one system on another,

6. the reinvention of techniques of writing or arithmetic triggered by the diffusion of incomplete information about a system that already existed,

7. the independent development of techniques of writing or arithmetic in different cultures with similar constellations with regard to the conditions that induced and constrained such development.

How writing and arithmetic developed in different geographical regions and under different historical conditions, and how they finally became globalized in the sense explained at the beginning of this paper, was determined by the interaction of such processes. Any explanation of specific historical developments of these cultural techniques has to take into account that they depended not only on the internal opportunities and constraints of the specific system of symbolic representation that was used, but also on interaction and exchange processes within and between cultures. From the viewpoint of this theoretical perspective, the development of writing and arithmetic from its beginnings to its globalization seems to be only insufficiently investigated. Disciplines such as archaeology, philology, linguistics and history of mathematics, which are concerned with aspects of this development, have contributed studies about the influence of specific conditions on specific developments, but the interdisciplinary integration of their results is still inadequate. Certain research deficits concern crucial details that require disciplinary research. These can only be identified by integrating the results of different disciplines.

As far as the origin of writing and arithmetic is concerned, in particular the origin of cuneiform writing, the situation can be briefly characterized in the following way. Three systems of writing (proto-cuneiform, proto-Elamite, Egyptian hieroglyphs) were created at nearly the same time, but their fates were different. Proto-cuneiform developed into cuneiform, which was disseminated and spread over great parts of the ancient Near East, influencing the development of other systems of writing, until it disappeared at some time in the first millennium CE. Proto-Elamite disappeared soon after its emergence; it was later replaced by cuneiform writing. Egyptian writing developed in parallel to the development of cuneiform writing into a full-fledged writing system for the Egyptian language. It survived along with cuneiform and disappeared at around the same time, but its use remained essentially restricted to Egypt itself. What was the reason for the near simultaneous emergence of the three systems? To what extent did they emerge independently of each other? How can their different fates be explained? How did the feedback of their different fates influence their internal development? These questions remain to a great extent unanswered, or the answers that are given are controversial. Some answers are commonly accepted, but are based on common-sense beliefs rather than a critical evaluation of the extant sources.

Concerning cuneiform writing in particular, it is well established that fully developed systems of writing and arithmetic existed at the latest in the first half of the second millennium BCE, in the Old Babylonian period. At this time, cuneiform writing was still used primarily for controlling economical activities, but in addition it was now applied to write down the tremendous corpus of Old Babylonian literature, letters and legal documents. Similarly, proto-arithmetical means and notations still played a major role in the context of economical administration, but Babylonian scribes had additionally created an unprecedented, powerful system of numerical notation: the sexagesimal positional system. This now developed into the esoteric system of Babylonian mathematics, independently of the development of writing. As a consequence, writing and arithmetic were no longer dependent on each other and their development was no longer constrained by their economical function.

Cuneiform writing and Babylonian arithmetic both show specific (from a modern point of view, odd) characteristics which they never completely lost. The logo-syllabic cuneiform writing system, as it was used for writing the Sumerian and the Akkadian languages, was and remained further based on a system that made extensive use of ideographs and graphemes representing syllables, most of which were phonetically polyvalent and, in addition, also homophonous to other graphemes. The resulting structural ambiguity could only be resolved by taking into account the syntactic and semantic context. The sexagesimal positional system of Babylonian mathematics was more seriously deficient since there was no sign for zero that could be used to indicate an empty position, and there was no way of indicating the absolute value of a numerical notation since there was no sign indicating the border between the whole number part and the fractional part of a notation. These characteristics of cuneiform writing and arithmetic require explanations to clarify how they emerged as an effect of the constrained development of the two cultural technologies.

Proto-cuneiform writing, on one hand, and Old Babylonian writing and arithmetic, on the other, mark the onset and the offset of complex developmental processes over a period of some 1,000 years. Many details of these processes have been successfully reconstructed, but they were mostly, if at all, interpreted in speculative historical narratives which are simplistic and often contradict knowledge achieved in other disciplines or by specialists working on another aspect of the historical process. What happened in the 1,000 years between the late Uruk and the Old Babylonian period still merits further study. Concerning the development of writing, for instance, it has been argued that the complex logo-syllabic structure of cuneiform writing resulted from the rebus principle, which allegedly determined the earliest stage of phonetization.[22] It is assumed that at a time when a stable syllabary did not yet exist, homophony between ideographic symbols for recognizable objects and phonemes occurring in names and abstract words, which could not be represented pictographically, was used ad-hoc to enable the symbolic representation of such names and objects. This would not only explain how ideographs were complemented with phonetic values, but also why the cuneiform writing system had so many homophonous and polyphonous graphemes. Rebus writing would automatically create homophony, since this is what it is based on, and polyphony, since the same object may have had different designations.

This simple explanation cannot be applied convincingly to the extant sources. The few examples of rebus writing that allegedly have been identified in proto-cuneiform texts are all problematic. But the next earliest group of texts, the texts of the ED IIIa period written around the middle of the third millennium BCE, already indicate the existence of a rudimentary, but stable, syllabary.[23] The assumption of a phase of rebus writing is thus merely a hypothetical construction concerning a time period from which no texts survive. But even if such a phase did exist, what could this explain? Why could the phonetic representation not remove the ambiguities allegedly inherited by the syllabary? Why was the syllabary never made less ambiguous at a later stage? Why should a hypothetic phase of rebus writing provide more important explanations than, for example, the transition from the representation of the Sumerian to that of the completely different Akkadian language, which had a proven influence on the construction of the syllabary of cuneiform writing?

The situation is similar in the case of the development of Babylonian arithmetic. There is a prejudice shared by philologists and historians of mathematics

[22] See Cooper in (Houston 2004, in particular 89–90).
[23] See Krebernik in (Bauer et al. 1998).

that the numerous forms of historically and geographically different numerical notations, which are characteristic of the cuneiform administrative documents, are only different symbolic representations of an underlying, common concept of number. This widespread prejudice materializes in transcription rules according to which the developing numerical notations of cuneiform sources are uniquely transcribed into modern Indo-Arabic numerals, or even into algebraic variables. Such transcriptions are of no use for any attempt to reconstruct the developing mental models underlying the development of numerical notations, which finally brought about the sophisticated—but deficient—arithmetic of Babylonian mathematics.

Looking at the broader picture of the globalization of writing and arithmetic, the situation is even more unsatisfactory. It is only too obvious that the spreading of writing and arithmetic in the ancient Near East and its neighboring regions resulted from various forms of cultural interaction and exchange.[24] As a consequence, the degree of mutual independence of the various systems and the ways in which they developed, under specific conditions, their specific structures and specific areas of application differed considerably between the early literate cultures. Only when the different ways in which systems of writing and arithmetic developed under existing constraints are reconstructed and explained can there be any hope of giving a convincing answer to the more general question of how often, and where, writing and arithmetic were created completely independently of each other.

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[24]See (Culican 1966; Helck 1979; Gibson and Biggs 1991; Charvát 1993; Potts 1993; Sasson 1995, vol. 4, part 9; Potts 1997).

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Chapter 7
Globalization of Ancient Knowledge: From Babylonian Observations to Scientific Regularities

Gerd Graßhoff

7.1 Science and Myth

Since the problem of demarcation between science and pseudoscience entered the history of science, the issue has troubled accounts of Babylonian intellectual activities. Astrology, magic, alchemy, divination, healing procedures and even meteorology seemed to flourish in the pseudoscientist camp, while only the newly emerging mathematical disciplines such as astronomy had the distinction of being a science.

This differentiation seems to separate two completely different intellectual activities. While the objectives of science include the acquisition of truth and the avoidance of errors by following methodical procedures, with reasonable decisions being made about the appraisal of hypotheses and the acquisition of empirical data, these goals are absent in the pseudosciences, which serve other, ideological orientations than those of truth. Consequently, their methodology does not necessitate the acquisition of knowledge and empirical observation. They do not serve the rational control of hypothetical supposition (Koch-Westenholz 1995; Rochberg 1999, 2004). Even as late as 1989, Otto Neugebauer was still inclined to hypothesize that there existed two cultures in Babylon (Neugebauer 1989, 393). Ulla Koch-Westenholz supports the received view on the nature of Babylonian omens. This study argues against almost all the major claims of the received view, and may, therefore, serve as a contrasting approach; in this paper, statements labelled as numbered "theses" aim to highlight the differences between the statements and the following general assessment by Koch-Westenholz:

> The legendary character of the "historical" omens, and the impossibility of some of the ominous events (such as the moon being eclipsed on the 20th day), strongly suggest that whatever was the basis of Babylonian divination, it was not empirical fact. Empirical observation may have played its part, but it was not fundamental. The solution must be sought elsewhere. Our own natural sciences are based on a premise so simple that it is usually taken for granted: things behave according to universally valid laws. It is our task to discover those laws, and the means to do so is observation, supported by the controlled experiment.

> In a similar fashion, Babylonian divination is based on a very simple proposition: things in the universe relate to one another. Any event, however small, has one or more correlates somewhere else in the world. This was revealed to us in days of yore by the gods, and our task is to refine and expand that body of knowledge. The means to do so is mystical speculation supplemented by observation. There is no evidence that the Mesopotamian scholars ever attempted to verify the results of their speculations by experiment. Nevertheless, the Neo-Assyrian astrologers undoubtedly believed in their craft and found it confirmed by events. For example, in Las 298, Akkullanu tells the king that "the series says in connection with this nisan eclipse: 'If Jupiter is present in the eclipse, all is well with the king, a noble dignitary will die in his place.' Did the king pay attention to this? A full month has not yet passed (before) his chief judge lay dead!" (Koch-Westenholz 1995, 18–19)

Since we know, from the surviving correspondence, the titles, work designations and even the salaries of the scholars who worked for the kings of the period, one can incontrovertibly state that no professional distinction existed between the realm of divination and the practice of scientific activities. If there had been a methodological distinction between practitioners of astrology and divination and those of mathematical astronomy, then it would be implausible to ascribe such a schism to the people.

Thesis 1 *No two cultures of scholars in ancient Mesopotamian societies existed, divided by the application of methodological scientific inquiry on the one hand and mythical reasoning on the other.*

The confirmation—or refutation—of this thesis needs to take into account the inferential treatment of an object of knowledge: if it is taken as the unequivocal assumption about conclusions and if it carries the burden of proof, this is taken to be a good indication that the people consider the assumption to be knowledge. Errors in their beliefs may be possible. The question of what is knowledge or what is known in antiquity cannot be adequately answered by reflective philosophical statements. Neither can it be decided upon by a linguistic analysis of words such as *episteme* or *techne*, nor even by the philosophical analysis of Plato's view of knowledge as justified true belief. More important is the practice of *how* knowledge is established and used in a critical epistemic context.

Thesis 2 *In ancient societies knowledge is characterized by the way it is established and is used for inferential derivations, and its potential to criticize other propositions.*

This movement away from content to the function of knowledge should lead to the classes of ancient texts being revised as either scientific or mythical according to modern disciplinary boundaries. Even the acclaimed distinction between *mythos* and *logos* needs to be reassessed accordingly.

A good example of how disciplinary distinctions can mislead the systematic interpretation of texts are the so-called *astronomical diaries*.[1] The title alone might send someone off in the wrong direction. For instance, the *diaries* record not only astronomical events, but also a large class of other equally important occurrences. Furthermore, it is all but clear whether they were recorded and compiled in the way that we write diary entries today. The *diaries* record weather phenomena processed by the same people for the same purpose as astronomical events, even though, in modern terms, these data belong to different realms of knowledge with possibly different methodological treatments. Closer inspection might establish that this group of texts is crucial to our understanding of the workings of early science.

7.2 Empirical Basis

It has only recently been established that, as a systematic compilation of observational data, the group of Akkadian texts called the *astronomical diaries*, dating mostly from the Seleucid era, is the foundation of Babylonian astronomy (Graßhoff 1997).

One oft-cited tablet of the *diaries* stands out on account of certain remarkable entries. In all other respects—reported content and formal linguistic structure—it is representative of the group of texts. The following translation and emendation is given by Bert van der Spek. Although the beginning of the tablet, which would include the complete date, is missing, the date can be reconstructed as year 5 of Darius III, month 6. It then continues in the following typical schematic manner:[2]

> Day 13 [20 September]: Sunset to moonrise: 8°. There was a lunar eclipse. Its totality was covered at the moment when Jupiter set and Saturn rose. During totality the west wind blew, during clearing the east wind. During the eclipse, deaths and plague occurred.
> Day 14: All day clouds were in the sky.
> Day 15: Sunset to moonrise: 16°. There were clouds in the sky. The moon was 3 2/3 cubits below [the star] Alpha Arietis, the moon having passed to the east. A meteor which flashed, its light was seen on the ground; very overcast, lightning flashed. [...]

Daily entries concerning astronomical or meteorological events cover the period until the end of that month. The tablet concludes with a small section on commodity prices and the planetary positions in the zodiac signs for that month.

[1] Published in three volumes, (Sachs and Hunger 1988, 1989, 1996).
[2] Cited after Spek, http://www.livius.org/di-dn/diaries/astronomical_diaries.html. Hermann Hunger has a slightly different reading and amendment, cf. (Hunger and Pingree 1989, 175–179). The content is fundamentally the same.

> That month, the equivalent for 1 shekel of silver was: barley [lacuna] kur; mustard, 3 kur, at the end of the month [lacuna]; sesame, 1 pân, 5 minas. At that time, Jupiter was in Scorpio; Venus was in Leo, at the end of the month in Virgo; Saturn was in Pisces; Mercury and Mars, which had set, were not visible. That month, the river level was [lacuna].

The sensational additional entry of this tablet reports the downfall of the empire and the defeat of Darius III by Alexander the Great at the battle of Gaugamela:

> On the 11th of that month, panic occurred in the camp before the king. The Macedonians encamped in front of the king.
> On the 24th [1 October], in the morning, the king of the world [Alexander] erected his standard and attacked. Opposite each other they fought and a heavy defeat of the troops of the king [Darius] he [Alexander] inflicted. The king [Darius], his troops deserted him and to their cities they went. They fled to the east.

This report is not only remarkable because of the events that it records. For the dissemination of knowledge it is important to note that the reports on these events were written after they had occurred, looking back at the end of the month. Meanwhile, the main scholar and his colleagues compiling the diaries continued to observe and record their observations in the traditional way. Like other new empire builders before him, Alexander in all respects allowed the scholarly tradition to continue, independent of the sometimes radical political and ideological changes the new leaders introduced. From all that we know about Babylonian astronomy, scientific practice and its results maintained their value, irrespective of contextual cultural differences.

Thesis 3 *In Mesopotamia scientific practices and knowledge acquisition persist throughout periods of social change. Scientific knowledge remains largely unaffected by changing cultural contexts and serves the same purpose to different users.*

At first glance the events seem to have been observed in a casual way and chronologically noted by one scholar. Yet a systematic analysis of these reports shows that they were formally and strictly arranged for each month, so that the entries resemble monthly reports containing systematic observations, and that canonical guidance was provided. Letters between the kings of the period and their scholars prove that this text group was indeed carefully assembled and that the kind of events included was well defined. The latter does not vary as the observers change. The organization of different observers at different places is even an attempt to ensure that the observations were as complete as possible and that other scholars double-checked the content. These texts systematically cover categories of events, which were specifically selected for a theoretical task.

Obv.
1: year 156, month xi, (the 1st of which was identical with) the 30th (of the preceding month), sunset to moonset: 18°; measured(?) (despite of) clouds(?) [...]
2: night of the 1st, all night very overcast; the south wind which was slanted to the east blew [...]
3: the south wind which was slanted to the east blew. Night of the 2nd, all night very overcast; to [...]
4: the south wind blew. Night of the 3rd, all night very overcast. The 3rd, clouds were in the sky. Ni[ght of the 4th, (...)]
5: the moon was 4 cubits below *h piscium*. The 4th, clouds and thin fog were in the sky [...]
6: in the afternoon, very overcast, the south wind blew. Night of the 5th, clouds were in the sky; the moon was 6 cubits below *a arietis*,
7: the moon having passed [...] cubit to the east; all night very overcast, the south wind blew.

Even though the observations cover six centuries, they are remarkably constant in composition. They constitute late Babylonian empirical records, which, after centuries of refinement, have a remarkable precision and temporal range of validity.

The signatures of the observers were not commonly recorded. In contrast to the *diaries*, as Mathieu Ossendrijver showed, theoretical astronomical texts authored in Uruk show the names of the tablets' 'owners' and those of the scribes. Figure 7.1 shows the temporal distribution of scholarly activities undertaken in Uruk during the Seleucid era, the years of which form the diagram's y-axis. A vertical bar represents the time period during which scholarly activities were carried out. The shallow (grey) bars show the scribe's activities; the solid (black) bars the activities of a tablet's "owner." Every tablet carries two names—that of the owner and that of the scribe—which are connected in the diagram by means of horizontal lines. The continuous (grey) background colour of the diagram shows that the activities were undertaken by only a few families. Although in most cases the owner and scribe came from the same family, there are notable exceptions. A scholar always started his career as a scribe. Once promoted to "owner," he is never recorded as working as a scribe again. Some entries make it clear that the 'owner' checked the validity of the tablet produced by the scribe. Therefore, the main function of the owner's name on the tablet was to take responsibility for its validity. The system established a form of quality control at the report and copy producing level. The *diaries* are one level higher: reports were collected for the monthly reports, from which the *diaries* were then compiled at a central place—the palace or the library. A critical examination and comparison of the texts with synchronous observations were probably undertaken.

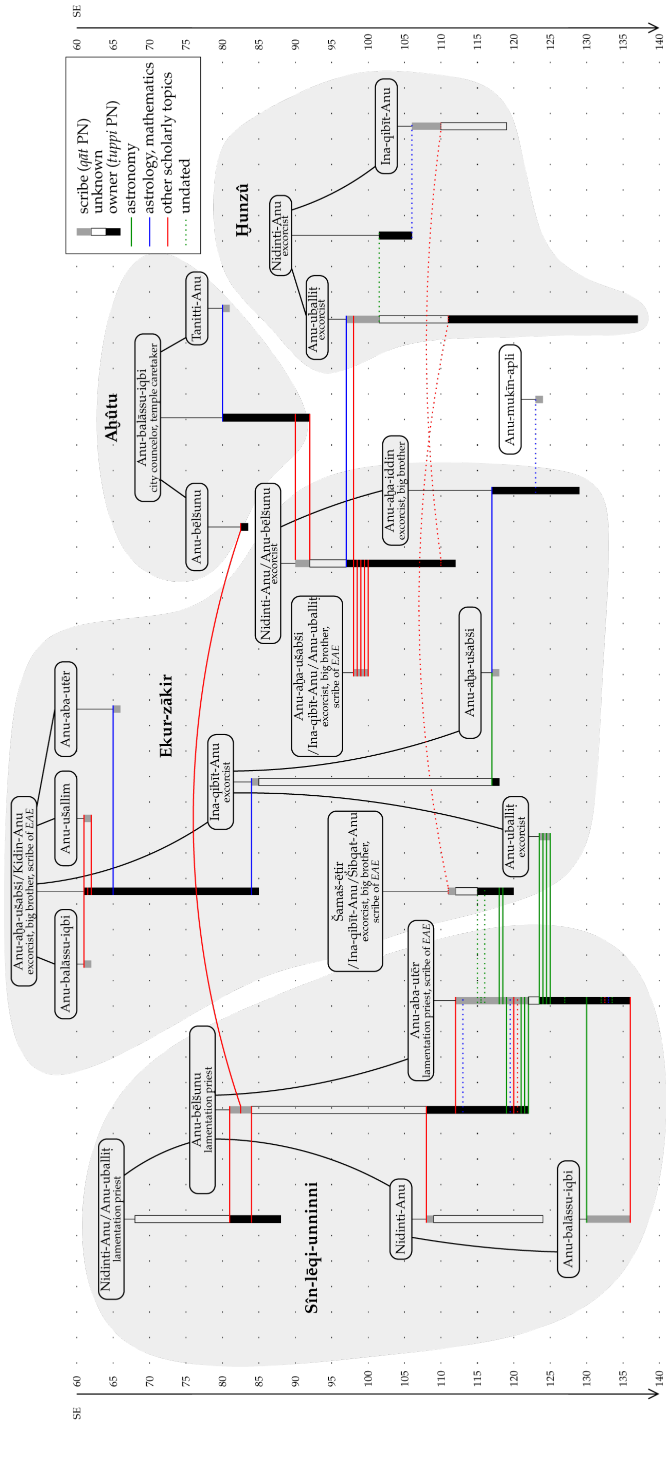

Figure 7.1: Schematic diagram showing the engagement of scholars as writers and "owners" of the astronomical cuneiform tablets authored in Uruk. The schema was provided by Mathieu Ossendrijver gratuitously, and is to be published in the proceedings of the 53rd Rencontre Assyriologique Internationale, Moscow/St Petersburg 2007.

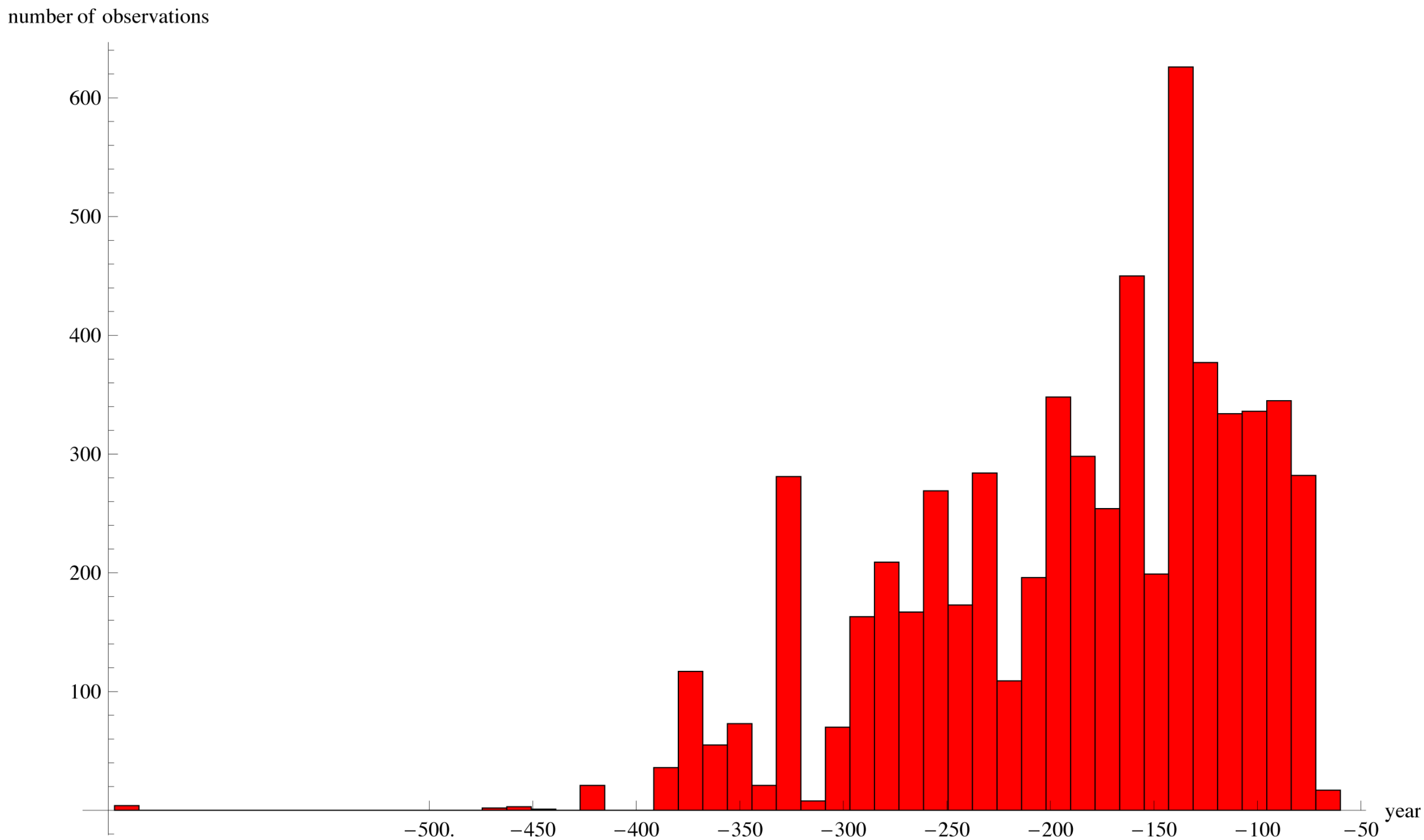

Figure 7.2: Distribution of observations in the *astronomical diaries*. The increase in activity in later times is due to distortions from the archaeological findings.

Even when the observations were carried out by several people at different places, their reports were collected, critically examined and synthesized into one representative datum, which consequently lost its individual observational background. The names of the observers are no longer an indication of the tablets' validity. Both the astronomical events as well as the summarized economic data were gathered in standardized ways. They were not exposed to the coincidental market observations of scholars who happened to be buying items at the weekly market. The *astronomical diaries* thus record types of events that were shaped and selected on the basis of centuries of theoretical reflection. The precise astronomical meaning of the recorded events could, therefore, be decoded (Graßhoff 1997).

Thesis 4 *As a source of empirical data, the* astronomical diaries *were systematically checked by a group of researchers. This communal effort was required in order to obtain a comprehensive and reliable data resource. Consequently, the empirical data therein are more than just the "protocol sentences" of individual observers.*

The long-term comparison of observations made at different places and sometimes with time differences of several centuries requires that the meaning of the terms describing the recorded events is constant and well controlled. A global distribution of the key concepts is, therefore, a precondition for finding patterns in the reoccurrences of natural events. If the meaning or practice of recordings and measurements had changed over the centuries or had been given new rules, the observational records would then have become incommensurable. As a result, ancient scholars tried to ensure that scholars were well trained and certifiably qualified in order to guarantee a common understanding.

Thesis 5 *The* astronomical diaries *are formal, observational recordings of momentous events that took place in the fields of astronomy, meteorology, economics and state, which were documented in the form of monthly reports.*

7.3 Regularities as Scientific Hypothesis

7.3.1 First-Order Regularities

The meteorological patterns of events are self-evident and they link the major classes of events recorded in the *diaries*: the fate of the state strongly depends on the fortunes of agriculture, which depend on the weather, which changes periodically with the seasons. The latter are defined by characteristic astronomical events, the most significant of which are the so-called heliacal risings and settings of celestial objects: shortly before sunrise (or sunset) an object rises (or sets) and becomes visible to the observer before the sun outshines the other objects. Stars typically have one day in the solar year when their heliacal rising occurs shortly before the sun rises in the east. Therefore, they are the best indications of specific days in the year. Since planets move across the stars, they do not signify specific dates in the solar year. Therefore, the first-order regularities of meteorological events describe events that reoccur on the same date of the solar year: spring, harvest, heavy rains and dry seasons. For Mesopotamia this works with impressive precision. Yet even these successful regularities could be improved. The methodology for improving regularities can be studied in the case of the history of astronomy: lunar eclipses are an important matter and they need to be accurately predicted. A first-order regularity would state that lunar eclipses can only occur at full moon, or on day 12 or 13, sometimes on day 14, of the month. If taken to be a material conditional, the regularity would be false, since we observe many full moons without an eclipse taking place. This does not make the regularity false! Ancient astronomers did not take these regularities to be material conditionals but as features which express *ceteris paribus* regularities: under additional (often unknown) conditions, an event will occur given its preconditions. A search for these additional *ceteris paribus* conditions could prove to be particularly enlightening about the development of early mathematical astronomy in Mesopotamia.

7.3.2 The Concept of Signs

A citation from Hermann Hunger and David Pingree lays down the standard view of the kind of knowledge that early Babylonian scholars were seeking:

> Omens can also be classified according to their predictions: some omens concern the king, the country, or the city; others refer to private individuals and their fortunes. One thing is to be kept in mind: the gods send the signs; but what these signs announce is not unavoidable fate. A sign in a Babylonian text is not an absolute cause of a coming event, but a warning. By appropriate actions one can prevent the predicted event from happening. The idea of determinism is inherent in this concept of sign. The knowledge about the signs is however based on experience: once it was observed that a certain sign had been followed by a specific event, it is considered known that this sign, whenever it is observed again, will indicate the same future event. So while there is an empirical basis for assuming a connection between sign and following event, this does not imply a notion of causality. (Hunger 1999, 5)

Though somehow empirically based, what exactly this kind of knowledge was remains obscure. Signs are certainly not absolute causes (who ever said that they were?), but what is the epistemology of a “warning”? Ancient scholars undoubtedly wanted to obtain knowledge about the connections between certain events, so that they could intervene and perhaps prevent an otherwise probable future event from occurring. Medical doctors find themselves in the same diagnostic and therapeutic situations: symptoms are analyzed in order to deduce unknown causes for illnesses, which hopefully can be cured or even prevented from happening. Yet this would only work if causal interactions were presumed, which is precisely what the Babylonians did for all kinds of regularities.

Thesis 6 *In Babylonian scholarship there is no methodological difference between causal reasoning, which aims to obtain knowledge about causal regularities, and causes that are indicated by signs. This applies to all kinds of domains of knowledge—from medical and meteorological to economical and astronomical knowledge.*

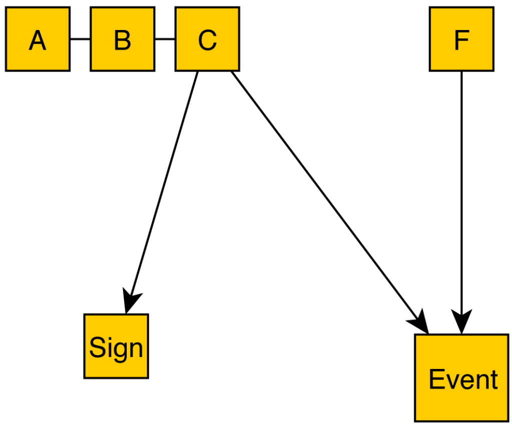

Figure 7.3: An epiphenomenal causal diagram for signs and effects.

The reason for the widespread misunderstanding of early empirical science is the following interpretation of expressions of regularities:

> Almost all omens are formulated as conditional clauses, "if x happens, then y will happen." The first part is called the protasis, the second part the apodosis. (Hunger 1999, 5)

It is common opinion that the logical form of omens, like many other Akkadian sentences that express regular occurrences, has the logical form of a material conditional: if-then relations are logically false only if the antecedent is true and the consequent false.

Yet, a number of different meanings could be read from the grammatical form of the construction, which starts with the word *šumma*, and is followed by the antecedent or *protasis* and then by a consequent (*apodosis*):

1. material conditional: “if socrates is a philosopher, then he is a wise man.”
2. definitional assignment: “if he is a bachelor, he has no wife.”
3. causal regularity: “if you strike the match, it will light.”
4. decisional sentence: “if you obey, you will succeed.”

For the interpretation it is sufficient to study the use of such regularity expressions in order to determine their meanings.

Thesis 7 *Expressions of regularity in early science denote complex causal structures such as epiphenomena.*

7.3.3 Rules of Inference

In *A Babylonian Diviner's Manual*, an ancient text edited by Leo Oppenheim, some rules of inference are articulated for the ancient scholar:

> The signs in the sky just as those on the earth give us signals. […] Their good and evil portents are in harmony [i.e., confirming each other]. The signs on earth just as those in the sky give us signals. Sky and earth both produce portents; though appearing separately, they are not separate [because] sky and earth are related. A sign that portends evil in the sky is [also] evil on earth, one that portends evil on earth is evil in the sky. When you look up a sign [in these omen collections], be it one in the sky or one on earth, and if that sign's evil portent is confirmed, then it has indeed occurred with regard to you in reference to an enemy or to a disease or to a famine. Check [then] the date of that sign, and should no sign have occurred to counteract [that] sign, should no annulment have taken place, one cannot make [it] pass by, its evil [consequences] cannot be removed [and] it will happen. (Oppenheim 1974, 203–205)

The following list of regularities is grouped according to phenomena. It is clear that the finding of regularities is an empirical question. The protasis is described as:

(25) “if the sky is constantly covered with a haze”
(26) “if after the sun has moved higher,
a star shoots and comes to a stop in front of it”
(27) “if the planet Venus becomes stationary in the morning
and its critical dates”
(28) “if the planet Mars which has seven names is seen
on the day of (its) opposition”
(29) “if the opposition of moon and sun”

(30) “if the first visibility of the moon and its ‘tiaras’ ”
(31) “if the moon is constantly surrounded by a halo
from the first to the fifth (var. thirtieth) day”
(32) “if a star is seen that has a crest in front and a tail behind
and the sky turns light”
(33) “if Adad sends lightning and his ‘hand’ is seen together
with the lightning”
(34) “if the constellation Pegasus is seen in the month Nisannu”
(35) “if a rainbow that is curved like the intestine(s) is seen in the sky”

The *diviner’s manual* predates the *diaries.* Its author does not disclose how empirical records or observations should be evaluated in order to obtain regularities. Yet, it is made clear in the following passage that regularities are *not* material conditionals. Rather, they are to be communicated in such a way that additional unknown causal factors are taken into account and because of which a predicted event might not occur.

> (47–52) These are the things you have to consider when you study the two collections [called] “if from the month Arahsamna on” [and] “if a star has a crest in front.” [when] you have identified the sign and [when] they ask you to save the city, the king and his subjects from enemy, pestilence and famine [predicted] what will you say? when they complain to you, how will you make [the evil consequences] bypass [them]?

It is important that all regularities are temporally determined. Therefore, all regularities are intrinsically linked to time periodicities, which are determined by astronomical periods.

> (53–63) In summa twenty-five tablets with signs [occurring] in the sky and on earth whose good and evil portents are in harmony you will find in them every sign that has occurred in the sky [and] has been observed on earth. This is the method to dispel [them]:
>
> (57–63) Twelve are the months of the year, 360 are its days. Study the length of the year and look [in tablets] for the timings of the disappearances, the visibilities [and] the first appearance of the stars, [also] the position of the Iku star at the beginning of the year, the first appearance of the sun and the moon in the months Addaru and [...] Flu, the risings and first appearances of the moon as observed each month; watch the ‘opposition’ of the Pleiades and the moon, and [all] this will give you the [proper] answer, [thus] establish the months of the year [and] the days of the months, and do perfectly whatever you are doing.

The last sentence serves as a warning (and encouragement) to scholars to practise according to scientific standards (although it is not called that). “Perfectly” in this context means that the scholar should make his observations according to standards, that is, according to reliable traditional practices and instructions. By concluding the text in this fashion, the author also makes it clear that perfect execution is something that can be verified by the community. Indeed, there exist a number of texts in which reports made by different scholars on the same events are critically compared.

Some of the observations recorded in the *diaries* are clearly derived from regularities—they are noted as such ("nu pap")—which indicates that there was a need for a complete or nearly complete set of observations. This was especially important for establishing the reliability of causal inferences—if one wants to ensure that regularities with no or only a few exceptions were recorded in the past. A complete set of observations is again vital when it comes to time recording, since everything that ensues depends on the proper recording of events in relation to the genuine astronomical time scale:

> (64–65) Should it happen to you that at the first visibility of the moon the weather should be cloudy, [the water clock(?)] should be the means of computing it, should it happen to you that at the disappearance of the moon the weather should be cloudy, the water clock[?] should be the means of computing it.

This is also valid when it comes to making weather prognostications. The following text is particularly interesting, since it contains instructions on how to obtain rules for forecasting the weather, rules that also apply to other meteorological texts:[3]

1 […for rain and flood] water do you have a prediction.
2 […] month Ajjaru; for Jupiter 72, 24 (or) 12 years;
3 [for Venus] 16 (or) 8 years; for Mercury 46, 21 (or) 13 years;
4 [for Mars] 47 years; for the sun 36 (or) 54 years;
for the moon 18 years.
5 [so much earlier] it was too early, it will be too early (also) now;
so much earlier it was too late, it will now be too late (also).
6 [so much earlier] there were clouds, there will be clouds (also) now;
so much earlier there was thunderstorm, there will thunderstorm (also) now.
7 [much] earlier there was heavy rain, there will be heavy rain (also) now; so much earlier …it was, it will be …now.
8 [much] earlier …it was, is will be …now;
so much earlier it was downpour, it will be downpour (also) now.
9 [much] flooding was during Adad, it will be flooding during adad (also) now; predict mass flood.

The above rules assume a principle of determinism in conjunction with astronomical periodicities, which always takes into account that additional factors

[3]Edited by Hermann Hunger.

on the conditional part are necessary for the future event is to occur or fail to occur. The text is made up of three parts: astronomical periods, then the statement that some constant time shifts can be applied, concluded by the enlisting of weather phenomena of increasing importance. This is a schema to build regularities of weather prognostications that work as well as schemes for astronomical predictions.

Thesis 8 *The text of the* diviner's manual *contains instructions on how to make empirically valid weather prognostications.*

7.3.4 The Construction of Causal Regularities

There exists an information flow schema that closely follows the instructions of these and similar tables.

1. The empirical basis is a chronological record of suspicious signs and events, with characteristically first-order regularities.

$date_1$	$event_1$
d_2	$sign_1$
d_3	$sign_2$
d_4	$sign_3$
d_5	$event_2$

2. correlations: $date_i[sign_1 \text{ } and \text{ } sign_2] \rightarrow event_1$
3. periodicities: $date_i + period[sign_1 \text{ } and \text{ } sign_2] \rightarrow event_1$
4. sign periodicities: $date_i + period \rightarrow [sign_1 \text{ } and \text{ } sign_2]$

The methodology of the functional understanding of these regularities follows those of causal reasoning (Graßhoff and May 2001; Graßhoff and Baumgartner 2004).

Thesis 9 *The application of the rule of causal reasoning generated knowledge about the correct regularities concerning astronomy, medicine, meteorology and other epiphenomenal structures.*

Once the empirical content of the *diaries* had been decoded, the question of the origin and development of Babylonian astronomy could be newly formulated. Otto Neugebauer participated in this reappraisal in the last two years of his life. Noel Swerdlow (1998) attempted to explain the genesis of planetary theory from the kind of observations that are recorded in the *diaries*, while the most plausible reconstruction of lunar theory was published by Lis Brack-Bernsen (1993; 1997). As early as the sixth century BCE, the first schematic calendars, in which astronomical regularities were employed, came into use. However, we still lack a comprehensive picture of the genesis of later Babylonian astronomy.

The transmission of knowledge in antiquity was first surveyed by Neugebauer in 1945 (Neugebauer 1945). It is now clear that, during the Babylonian period, knowledge was disseminated to all neighbouring cultures without undergoing change; its superiority was incontrovertible. The analysis of the *diaries* and their pivotal role as the empirical basis for various branches of the sciences in antiquity are also evidence that science was, already then, a global enterprise: even empirical knowledge by this time assumed well-established public criteria of those events that were the subject of scientific inquiry. Thus, in conclusion each datum in the *diaries* possesses generality, independent of places, cultures and contexts.

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Chapter 8
The Creation of Second-Order Knowledge in Ancient Greek Science as a Process in the Globalization of Knowledge
Mark Schiefsky

Between 600 BCE and 200 CE Greek philosophers and scientists developed a number of second-order concepts that exerted a massive influence on the development of our modern global science. These include the notion of mathematical proof (exemplified by Euclid's *Elements*), geometrical models of the heavens with quantitative predictive power (Ptolemaic astronomy), and the idea that medical treatment must be based on an explanatory theory of the cause and cure of disease. The primary question addressed in this paper is this: in what sense can the creation of these concepts or "images of knowledge" (Elkana 1986) be viewed as part of a long-term process of the globalization of knowledge?

The ancient Greeks traced the origin of many aspects of their culture to the neighboring civilizations of Egypt and the Near East. Yet modern scholarship has often been reluctant to adopt such a perspective. That the Greeks had ample opportunity for contact with neighboring cultures in the Hellenistic period and thereafter is clear. In the aftermath of Alexander's conquests Greek culture became dominant across the Mediterranean world, even if the precise character and limits of Hellenization varied from place to place (Momigliano 1975). But the case for widespread cultural contact and its impact during the formative period of Greek culture has only recently begun to be made systematically on the basis of archaeological and linguistic evidence (Burkert 1992, 2004). The evidence for connections is early and extensive. In the eighth century BCE a most important instance of cultural diffusion took place when alphabetic writing, which had been developed in Phoenicia, was adapted to the Greek language. Motifs with close near Eastern parallels can be discerned in both the art and literature of the period. The migration of specialized practitioners or craftsmen supplies a plausible mechanism for much of this diffusion. The spread of techniques such as ivory carving and bronze working testifies to close apprenticeship between Greeks and eastern craftsmen (Burkert 1992, 22). Artistic representations and linguistic evidence both support the theory that divination spread from Mesopotamia to the West, presumably as a result of the migration of expert practitioners (Burkert 1992, 46–53).

The upshot of this work has been to change the terms of the debate: the burden of proof is now on those who would deny that contact with neighboring civilizations contributed in a significant way to the Greeks' distinctive cultural achievements. Yet it also raises a challenge to define more precisely the modalities of cultural influence, which have too often been conceived of as a matter of simple "borrowing" or "transmission." In examining the history of science it is also important to distinguish between different kinds of knowledge: to say that metalworking techniques spread from the Near East to the Greek world is one thing, but to claim that Euclidean geometry was adopted from Egypt quite another. In what follows I would like to offer a general characterization of the impact of cultural contact on the development of Greek science based on a distinction between two kinds of knowledge and two modes of cultural diffusion.

1. *First-order and second-order knowledge.* First-order knowledge is knowledge about the world, whether theoretical or practical in orientation; it may be a knowledge of how things are, or a knowledge of how to do or make things. By second-order knowledge I mean knowledge that derives from reflection on first-order knowledge: for example, a method for generating new procedures. Second-order knowledge is also an "image of knowledge" insofar as it sets out a conception or norm for what knowledge is in a particular domain. The idea of mathematical proof is a paradigmatic second-order concept, since it involves a specification of the conditions under which mathematical assertions can be accepted as true.
2. *Modes of diffusion.* I distinguish between diffusion through borrowing, in which a cultural product is transmitted from one culture to another more or less unchanged, and stimulus diffusion, in which the exposure to a product of one culture stimulates a parallel development in the other. As a modern example of the latter A. Kroeber, who coined the term "stimulus diffusion," cites the way in which the import of Chinese porcelain to Europe prompted Europeans to engage in a systematic search to find the materials and discover the procedures to replicate it (Kroeber 1940). In such a case there is clearly cultural influence, which may even be essential for the invention in the receiving culture: Europeans might never have had the idea to create porcelain, had they not seen the Chinese examples. But there is no simple transmission of knowledge.

My main argument is twofold: first, insofar as borrowing played a role in the development of Greek science it was generally limited to first-order knowledge; second, the notion of "stimulus diffusion" is helpful for understanding the development of second-order knowledge in Greek science. The spread of craft products and specialized practitioners tended to transmit first-order knowledge of methods and procedures, not second-order knowledge of how those methods were found. In that sense the Greek forms of second-order knowledge are distinctively Greek achievements. But the enrichment of first-order knowledge prompted by cultural contact contributed to their development in ways that may well have been essential to stimulating critical reflection. This is so in two ways: by augmenting the base of first-order knowledge, and by presenting specific examples or results that called out for explanation and reflection. As Aristotle observed, wonder is the origin of philosophy, and the Greeks certainly experienced wonder when confronted with the achievements of the much older civilizations of Egypt and Babylon (cf. Herodotus). Such wonder, I am suggesting, was an important factor in the development of second-order knowledge in Greek science.

Two preliminary points are crucial. First I do not claim that the Greeks *invented* second-order knowledge, or that the specifically Greek forms of second-order knowledge are the only such forms. Second-order knowledge can develop wherever there is substantial reflection on methods or procedures, and such reflection is present in many cultures and many contexts (Elkana 1986). My concern is with the development of specific kinds of systematic second-order reflection in the Greek context. Second, my reason for emphasizing these forms of second-order knowledge is their enormous influence on the subsequent development of science. I do not mean to suggest that the history of science is limited to a history of second-order knowledge, nor that these are the *only* forms of such knowledge that were influential.

With these points in mind I now turn to a brief examination of four related areas of Greek science in which contact with foreign cultures played an important role: cosmology, mathematics, medicine and astronomy. My discussion makes no claim to comprehensiveness. Its goal is the much more limited one of exploring how the distinctions I have set out above can provide a useful framework for analyzing the development of Greek science as a process in the globalization of knowledge.

8.1 Cosmology

By "cosmology" I mean a more or less systematic account of the structure of the world and the place of human beings in it. In this sense cosmological thought is a feature of the mythology and literature of almost all cultures, including of course ancient Mesopotamia and Egypt as well as Greece. But the type of cosmological thought that developed between the sixth and fourth centuries BCE in ancient Greek culture is quite different from what came before. Three features of these systems are important for present purposes.

1. First, these Greek cosmologies offer a certain kind of explanation of the universe. They typically seek to reduce the diversity of observable phenomena to the interaction of a small number of factors, which behave in consistent ways in a wide variety of contexts. And they are "rational" in the sense that they are supported by explicit reasons and arguments. For example, Anaximenes explains all physical transformations by condensation and rarefaction, and offers evidence (the behavior of breath exhaled from the mouth) that heating and cooling can be reduced to those processes.
2. Second, early Greek cosmologies typically envision the large-scale structure of the universe in terms of geometrical models with a high degree of sym-

metry. For example, Anaximander conceives of the sun, moon and stars as apertures in a set of concentric rings, which are supposed to explain phenomena such as eclipses and the phases of the moon.

3. Finally, analogies with various crafts are an important source of both the particular explanations and the geometrical models characteristic of this tradition. Thus Anaximander's cosmic rings are likened to wheels, while Anaximenes likens condensation and rarefaction to the production of felt from wool.

The earliest Greek cosmologies are an example of first-order knowledge; they attempt to set out images of the world rather than images of knowledge. Yet in their emphasis on systematic, reductive, and general explanation they represent a new kind of first-order knowledge that is quite different from anything to be found in ancient Mesopotamia or Egypt. Whatever parallels there may be between the cosmic geography in a Babylonian text and some Greek system are not as significant as the context in which such a system is embedded: they are, at most, a kind of "scaffolding" (Livingstone 1986; Burkert 1992, 66–69). As Rochberg writes:

> Mesopotamian cosmologies are reflected in texts whose goals were assuredly not to construct a definitive cosmic picture to serve as the framework for inquiry about natural phenomena. (Rochberg 1993, 51)

That, of course, is precisely what the Greeks *were* doing. Yet it is surely no accident that this particular tradition in Greek thought begins in Miletus, at the heart of the cultural crossroads that was Asia Minor in the sixth century BCE. Through Parmenides' critique in the early fifth century BCE Greek cosmological thought becomes second order, as explicit standards for the validity of cosmological accounts and arguments are developed and articulated. But this critique of course presupposes the existence of the earlier systems.

8.2 Mathematics

A distinctive achievement of early Greek mathematics is the development of the second-order concept of proof, which implies analysis of the conditions under which mathematical assertions can be accepted as true. While a concern with proof is the hallmark of Greek mathematics as represented by authors such as Euclid, Archimedes and Apollonius, it is not a feature of all Greek mathematical knowledge or even all Greek mathematical texts. Texts such as Heron of Alexandria's *Metrica* (probably first century CE) testify to another type of Greek mathematical knowledge, one concerned with practical problems of calculation and mensuration rather than deductive proof. Such texts may reflect the diffusion of much older techniques from the near East (Neugebauer 1957; Høyrup 1996). While there is very little direct evidence, knowledge of basic arithmetic and calculation techniques may well have spread to the early Greek world from the ancient near East (Waschkies 1989).

My main concern here is with the notion of mathematical proof as we find it in Euclid's *Elements*, which developed between the beginning of the sixth and end of the fourth centuries BCE. Since we have almost no Greek mathematical texts from this period, any reconstruction of these developments is unavoidably speculative. What we can do is compare the *Elements* itself with the extraordinarily rich sources for Babylonian mathematics that date from the third millennium BCE to the Seleucid period. Recent work has demonstrated the existence of significant second-order reflection and cognitive development over the course of this long tradition. In particular, the development of the sexagesimal system at the beginning of the second millennium opened up new conceptual possibilities that led to significant changes in mathematical practices (Damerow 2001). Though the texts' characteristic mode of presentation is that of problems to be solved, in many cases the "problems" considered do not correspond to any real-world situation, and are clearly generated by second-order reflection on the standard procedures. But it also seems clear that these developments were very different from those that took place in Greece; moreover the second-order reflection in the Babylonian tradition remained largely implicit in the written sources, making its transmission much more difficult.

The case of the Pythagorean theorem illustrates the problematic nature of any claim of a straightforward transmission of Babylonian mathematics to the Greeks. That the mathematicians of the Old Babylonian period "knew" the Pythagorean theorem is a widespread claim that goes back to the pioneering work of Otto Neugebauer in the early twentieth century; sometimes it is said that they "knew" the theorem but could not "prove" it. But on closer examination this apparently straightforward claim goes to the heart of the differences between Euclidean and Babylonian mathematics (Damerow 2001). While a number of early texts attest to the scribes' recognition that the Pythagorean relationship can be applied in the solution of certain problems, there is no evidence of any recognition that the relationship holds only under certain conditions (i.e. only for right-angled triangles). Rather, the necessity of the relationship within the Babylonian context follows from principles that are quite different from those that underlie Euclidean geometry. Moreover, a close analysis reveals that contexts in which it would be reasonable from the modern (and also Euclidean) perspective to infer that the scribes had knowledge of the theorem in its full generality can be explained in other ways (Damerow 2001). Similar observations apply *a fortiori* to the claim, widespread in mid-twentieth century scholarship, that the Babylonians developed a kind of algebra that was somehow transmitted to the Greeks and then reformulated in geometrical terms (the so-called "geometrical algebra" supposedly exemplified in Book 2 of the *Elements*). Recent work by Jens Høyrup has shown that much of Old Bablyonian mathematics can itself be characterized as a kind of "geometrical algebra" insofar as it relies on geometrical visualization to compute relationships between lines, widths and surfaces (Høyrup 2002). Diagrams played an important role in Babylonian mathematical practice, as even a cursory examination of the cuneiform literature shows. Yet the Babylonian and Greek traditions make use of diagrams in quite different ways, and a close comparison with Euclid reveals more differences than similarities. Whereas Babylonian mathematics is focused on measurement and calculation the Greek texts eschew any mention of numbers; and the inductive character of Babylonian mathematics, in which generalizations are inferred from the solutions to specific problems, is opposed to the Euclidean practice of inferring general conclusions from explicit axioms (Robson 2008, 274–284; Rudman 2010, 195–211). Aside from the general similarity of subject matter, there are few close affinities between the two traditions.

The factors that drove the development of the notion of proof in the Greek context seem to have been quite different from those which stimulated critical reflection in the Babylonian scribal schools. They include:

1. the development of new mathematical concepts including incommensurability, which both reflected and called for analysis of the conditions under which they held of mathematical objects;
2. the rapid increase in the number of mathematical results discovered by the investigation of such concepts;
3. the development of a new kind of notation in which letters of the alphabet are used to refer to geometrical entities in the diagrams;
4. the possible impact of an emerging concern with second-order knowledge in the cosmological tradition in the wake of the Parmenidean critique (Szabó 1978).

An additional factor *may* have been familiarity with some of the results of Babylonian mathematics as transmitted by practitioners. For example, a Babylonian school-text (BM 15285) contains a series of diagrams illustrating an argument strikingly similar to the famous passage on "doubling the square" in Plato's *Meno* (82–86) where Socrates leads a slave boy to recognize a special case of the Pythagorean theorem (Damerow 2001, 240–243). Mathematical knowledge as expressed in diagrams of this kind could have been transmitted relatively easily and might have stimulated the Greeks to develop their own accounts of the conditions under which such results could be said to hold. Still, it is important to note that no concrete evidence of such transmission is at hand, and the possibility of influence via stimulus diffusion remains entirely circumstantial.

8.3 Medicine

I shall concentrate here on early Greek medicine as represented in the texts of the Hippocratic Corpus, a collection of writings by various authors dating largely from the fifth and fourth centuries BCE. These texts vary widely in their approach to medical theory and practice. Some of them display a number of features in common with Mesopotamian and Egyptian medical texts in regard to both form and content. The treatise *On Diseases 2,* for example, consists of a catalog of diseases indicating the signs by which they can be recognized and the appropriate treatment. There are affinities between the therapies mentioned in Greek texts and earlier material (Goltz 1974; Geller 2010). Further affinities have been noted between Greek concepts such as "breath" and "phlegm" and Babylonian notions (Geller 2007), as well as between the Greek notion of "residues" and the pathological agents of Egyptian medicine (Steuer and Saunders 1959). Greek doctors travelled widely over the ancient Mediterranean world, with some (e.g., Democedes of Croton) ending up at the Persian court. Egypt is known as a land famous for drugs as early as Homer's *Odyssey.* There is thus no reason to reject the notion that the first-order knowledge base of Greek doctors was significantly enriched by contact with the medical traditions of the Near East and Egypt.

But we can also identify in the Hippocratic texts a concern with methodological reflection that is not present in the material from the neighboring cultures. In particular, the conception of medicine as a form of expertise (*technê*) that has a basis in explanatory theory is developed by some (though by no means all) of the Hippocratic writers. This development was a result of several interacting factors. The impulse toward highly reductive explanation that can be traced in early cosmological thought had its impact on medicine, as the cosmological theorists tended to speculate on the construction of the human body or the causes of health and disease. The impact of this approach can be detected in a variety of Hippocratic treatises, and prompted the development of new methodological theories drawing on medical experience (Schiefsky 2005). Within the medical tradition itself we can trace a rapid growth in the extent of first-order medical knowledge; this is exemplified by texts like the Hippocratic *Epidemics*, which contain case histories of disease collected by practitioners in their travels around the Greek world. The *Epidemics* testify to an ongoing engagement with the problem of relating general rules to particular cases, for as well as individual case histories they also contain an extensive body of prognostic and therapeutic generalizations that are closely related to the material in what is perhaps the most representative and influential Hippocratic text of all, the *Aphorisms.* The geographical range of the Greek doctors also prompted reflection on the conditions under which generalizations such as those expressed in the *Aphorisms* could be considered valid, for a rule that held under one set of climatic or geographical conditions might not hold elsewhere. The important early treatise *Airs, Waters, Places,* for example, sets out a general theory of the effects of environmental factors on human beings, and incorporates it into a wide-ranging ethnographic discussion of foreign lands and peoples. Similarly, the treatise *Prognostic* ends by saying that the prognostic "signs" it sets forth will be valid everywhere, not just in certain locales. Reflection on geographical variation and individual differences stimulated the development of general theories of the working of humoral factors such as phlegm and bile, which were supposed to explain the effects of the environment on all individuals *wherever* they might be located, and *whatever* their constitution might be.

Thus in medicine, as in mathematics, reflection on the conditions under which certain generalizations held stimulated the drive toward theoretical justification and the clarification of basic concepts. The Hippocratic texts themselves amply document this critical reflection, and there is no reason to think that it was the result of borrowing or transmission from Egypt or Mesopotamia. The major impact of the Greeks' longstanding contact with the medicine of those lands seems to have been an enrichment of the stock of first-order medical knowledge possessed by the Greek doctors: knowledge of therapies, procedures, techniques. This was by no means insignificant. Insofar as procedures worked, or were thought to work, they became a reliable starting point for reflecting on *why* they worked.

8.4 Astronomy

The crucial development is that of the astronomical model as a geometrical representation that can be matched to observational data so as to yield exact quantitative predictions. The development of the so-called "two-sphere" model, with the spherical earth inside a spherical heaven that rotates once a day, is securely attested by the middle of the fourth century BCE; this explained a wide variety of observations of the movement of the sun, moon and stars (Kuhn 1957). The precise stages of its development are obscure, but a plausible case can be made that reflection on the nature of technical instruments and procedures played an important role, as in other areas of early Greek cosmology (Szabó 1992). By the middle of the fourth century BCE, we have evidence of a geometrical model (Eudoxus' theory of concentric spheres) that was clearly intended to represent the more complex features of planetary motion. Though this was a remarkable display of geometrical ingenuity that provided a qualitative explanation of phenomena such as retrograde motion, it is unclear whether it was intended to yield exact quantitative predictions.

Mathematical modeling of planetary phenomena with the goal of exact prediction arose first in Babylon, and reached the pinnacle of its development during the Seleucid period (Neugebauer 1957). Instead of constructing geometrical models of the cosmos, the Babylonians used combinations of arithmetical sequences to model the recurrence of phenomena such as the beginning or end of a planet's retrograde motion. The Babylonian approach aims at determining the time of recurrence of these periodic phenomena, while the Greek geometrical models allow the determination of planetary longitudes at any given time. The sophisticated models of Seleucid-era Babylonian astronomy were clearly the fruit of much second-order reflection. Procedures had to be developed for the modification of arithmetical schemes to fit observational data; a key technique is the isolation of variation in one phenomenon so that the variation in another can be studied (Neugebauer 1945; Swerdlow 1998). But the second-order reflections associated with these developments are not expressed in the texts themselves. Indeed even the methods used to generate the predictions are not normally expressed; most of the texts are ephemerides from which the methods of computation (and *a fortiori* the general development of these methods) must be laboriously reconstructed. The scribes do not seem to have committed their methods to writing; nor did they record whatever ideas they may have had about the meaning or general significance of the periodicities that their work so accurately represented.

The spread of these Babylonian methods across the Greek-speaking Hellenistic world is the most well-documented and extensive case of the transmission of scientific knowledge in the ancient Mediterranean world. That Hipparchus in the second century BCE and Ptolemy in the second century CE used Babylonian parameters in constructing their geometrical models has long been recognized. But it is not just a question of adopting Babylonian parameters: Babylonian methods also spread across the Greek-speaking world to an extent that has only recently become clear (Jones 1991, 1996, 1999). Not only Hipparchus himself, but also pre-Ptolemaic writers such as Hypsicles and Geminus make use of Babylonian methods, often without drawing attention to their provenance (Evans 1998; Berggren and Evans 2006). A number of papyri from Greco-Roman Egypt indicate that practitioners of astronomy or astrology adopted the Babylonian methods for the purpose of prediction, though these texts testify to some significant adaptations of these methods as well as translation into the conceptual framework of the Greek geometrical tradition (Jones 1996, 1999). As usual, knowledge is transformed in the process of transmission.

The adaptation of Babylonian arithmetical methods alongside the Greek geometrical approach led to a methodological tension that was resolved only in the work of Ptolemy. The Babylonian methods yielded accurate prediction, but it was not at all clear why they did; unlike the Greek geometrical models, they did not have any obvious cosmological significance. While authors such as Hypsicles and Geminus do not seem to have perceived any tension in this situation, it is clearly present in Ptolemy, and was surely an important factor that prompted him to recast mathematical astronomy on strictly geometrical lines in the second century CE. His remarks in the *Almagest* on the inadequacy of all earlier attempts to offer theories of planetary motion are as much a criticism of the Babylonian or "Greco-Babylonian" approaches as they are a claim to his own original achievement (*Almagest* 9.2; cf. Neugebauer 1945). Ptolemy made use of Babylonian parameters, which were the essential foundation of a system with quantitative predictive power, but the diffusion of Babylonian methods stimulated him to develop his own strictly geometrical approach. The end result was the Ptolemaic system, a powerful fusion of highly accurate prediction with an overarching cosmological framework which, despite internal tensions, dominated astronomy in the Islamic and European Middle Ages down to Copernicus. Here, then, in the best-documented case of the diffusion of scientific knowledge that we have from antiquity, we find clear evidence both of the transmission of Babylonian methods to the Greek world, and of their role in stimulating the development of a distinctively Greek approach.

8.5 Conclusions

I hope that this survey, however brief and speculative, has at least succeeded in showing the usefulness of the concepts I have introduced for understanding the impact of Egypt and the Near East on the development of Greek science. Contact with these cultures enriched the first-order knowledge of the Greeks in all the fields we have discussed. Insofar as borrowing occurred it was largely restricted to such knowledge; in this way the knowledge traditions of Egypt and the Near East provided an important stimulus to critical reflection and the development of second-order knowledge. Finally, the material I have surveyed suggests that second-order knowledge tends not to be transmitted when it is not made explicit in written texts. Hence the influence of the distinctively Greek "images of knowledge" in the subsequent history of the globalization of knowledge is at least partly due to the large amount of methodological discussion that is characteristic of many Greek texts.

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PART 2: Knowledge as a Fellow Traveler

Chapter 9
Survey: Knowledge as a Fellow Traveler
Jürgen Renn

9.1 The Stratification of Knowledge and the Historical Superposition of Globalization Processes

Usually scientific knowledge is conceived as being produced locally and valid globally. The distinction between a local context of discovery and a global context of justification may be labelled as "local universalism." It presupposes that, once global scientific knowledge is available, local conditions can only affect its application, interpretation or the choice of problems, but not modify its nature. Against this background, it is surprising that, in spite of the powerful political and economic globalization processes of the recent past and the globalization of science proceeding for centuries, today's world of knowledge is anything but homogeneous. Underneath common standards, methodologies and widely accepted results of science, there is still a great variety of local traditions, of ways to choose problems, to interpret their solutions, to integrate scientific knowledge into belief systems and societal processes. The same holds, more generally speaking, for the ways in which knowledge shapes our identities, informs our practices and pervades our social existence. It is hardly possible to understand this diversity and its relation to ongoing globalization processes without taking account of the fact that knowledge is stratified in a way similar to the stratification of geological layers, each coming with its own, often dramatic, history. The knowledge we deal with today is the result of history, of course. It is, more precisely, also the result of a historical superposition of globalization processes in which second-order knowledge, in particular in the form of images of knowledge shaping its societal role, has continued to accumulate in such a way that later layers interfered with earlier ones, without, however, eradicating them completely. Considering that bodies and images of knowledge are intertwined in a virtually endless historical chain of processes of reflection, local universalism has thus to be replaced by a global contextualism as a perspective from which to understand the globalization of knowledge in history.[1]

Over long periods of human history, knowledge was disseminated in connection with power and belief structures. Knowledge spread across long distances or over vast areas as a by-product of other diffusion processes, for instance, the expansion of empires or the spread of religions. These processes may be of transregional

[1]See chapter 25.

and cross-cultural character, but they may also be corridor-like, connecting distant regions by a thin, often indirect and fragile chain of transmission, for instance, a trade route like the Silk Road or the Jesuit mission to China.[2] Such corridors are of a special kind, holding the world together, but effacing or mystifying the distant partners in communication.[3]

As knowledge is but a fellow traveler in these processes, participating in their dynamics without governing it, the results of transmission are often only of a transitory nature, but a long-lasting sedimentation of at least some achievements is nevertheless possible, such as practices of writing and calculating which later became relevant to the appropriation of scientific knowledge. This kind of knowledge globalization began with the emergence of institutions bundling cultural activities, such as centers of trade and production, states and world religions.[4] As a consequence, transmission processes themselves also became institutionalized. Commercial, military and missionary activities provided new stimuli for knowledge transmission.

In spite of the transient and sometimes even ephemeral contexts of these globalization processes, they kept large parts of the world connected over long periods of time by common religious, economic and cultural traditions, through the exchange of technologies, practices and ideas, or through knowledge encapsulated in writing. This connectivity, however, did not lead to a uniformity of the contexts in which knowledge was being produced, disseminated and appropriated. Scientific knowledge, in particular, remained a fellow traveler until it became instrumental in shaping the economic bases of societies—which did not happen before the early modern period. By that time, the rapidly spreading scientific knowledge had begun to take root in an economically, politically and culturally diverse landscape that had also been shaped in part by earlier processes of globalization. The modern globalization of scientific knowledge that took place within this landscape thus depended on these earlier processes and their sediments.

Religious or quasi-religious traditions, such as philosophical movements or state ideologies, played a special role. These traditions, especially the world re-

[2]For a discussion of the Silk Road and relevant literature, on which the following is based, see (Rezakhani 2010; Haussig 1988, 1992). The name "the Silk Road" (*die Seidenstraße*) for the commercial routes passing through the Tarim basin into Transoxania goes back to the German explorer and scholar Baron Ferdinand von Richthofen. Silk, however, was not necessarily the only and not even the dominant trade item. Also, the Silk Road hardly served the Roman and the Chinese empires, at the extremes of the Eurasian continent, as a venue for direct interaction. The main point for our purposes is rather that the Eurasian continent remained over long historical periods connected by a network of weak ties, cf. (Granovetter 1983; Malkin 2011). The reconceptualization of the "Silk Road" in this sense remains an open question for research. For a discussion of the Jesuit mission to China, see chapter 11.

[3]Several contributions to this volume argue that, given the possibility of diffusion and conceptual similarities, the burden of proof is upon those who deny an underlying spread of knowledge, for example, chapter 10, section 10.5.

[4]See (Wallerstein 1989). Wallerstein reconstructs the emergence of centers and peripheries in an expanding European world economy. Less Eurocentric perspectives can be found in (Lippmann Abu–Lughod 1993, 75–102) and (Stern 1988, 829–872).

ligions, were not only most effective in the large-scale spread of knowledge associated with them, even across geographical, political and economic boundaries, they also provided and continue to offer overarching second-order epistemic frameworks governing the value and role of knowledge for societies and individuals. As a result of the historical superposition of globalization processes involving such frameworks, the modern knowledge economy includes large subsystems with distinct social, epistemological and normative features, such as normative Islam or Chinese medicine. These subsystems have proven relatively immune to the homogenization effects typically associated with globalization processes. This stability, however, is not just the result of the persistency of traditional settings, as it may appear, but is also due to a characteristic lack of reflexivity of modern science compared to religious or quasi-religious frameworks regarding questions of sense, purpose and identity. This instrumental character and lack of reflexivity of science is in effect often compensated by the epistemic frameworks inherited from prior history or from earlier phases of globalization. The very fact that science does not—and perhaps cannot and should not—play the role of homogenizing cultural identities as well may thus be due less to its intrinsic nature than to its role in historical globalization processes, having emerged as a fellow traveler itself.[5]

9.2 The Accumulation of a Potential for Science

As discussed in Part 1, from the third millennium BCE at the latest, the existence of trade routes connecting centers of early urbanization, for instance Egypt, Mesopotamia and the Indus valley is well documented. Technical innovations such as the development of bronze technology enhanced the need for raw materials, in this case of copper and tin, which had to be procured through an extended network of trade routes. Thus local technical, economic and political developments and the growth of networks reinforced each other. By the second millennium, large empires had emerged in Western and Eastern Asia, from Egypt in neighboring Africa, via the empires of Mesopotamia and the Hittite Empire in Anatolia, to Shang and later Zhou, China. In the middle of the first millennium, the Persian Empire extended from the Nile to the Indus and constituted an important conduit between Western Asian and Indian cultures. The Achaemenid Persian Empire, in fact, encompassed both Mesopotamia and parts of West India and Pakistan, where the easternmost Achaemenid-controlled satrapies were located (Potts 2007). This political "umbrella" created the conditions in which knowledge and technology transfer could occur within the boundaries of a single empire. Later, the Hellenistic empires of Alexander the Great and his followers, the Roman Empire, and Islamic rule established extended interaction spheres between different cultures.

[5]While Stengers (1997) is right in emphasizing that the knowledge systems of science tend to be closed worlds comprising their own control strategies and criteria of truth, this of course does not exclude multiple interfaces with other knowledge systems, which are often capable of interfering with or even overruling those intrinsic to science. Science thus never evolves autonomously, but always as part of larger knowledge systems.

The impact of such empires on social and cultural connectivity, their territorial expansivity, their reliance on extended commercial exchanges, and their continuous struggle with neighbors and nomadic populations supported (as was discussed in chapter 3) the spread of knowledge with more or less practical relevance to the functioning of these empires. This happened not withstanding the fact that empires also made attempts to keep certain knowledge secret, such as smelting technologies among the Hittites or Greek fire in the Byzantine Empire.

At the same time, wide-ranging empires contributed to the accumulation of a global potential for science over long periods of time. Consider the example of the Islamic Empire which connected the Mediterranean, the heart of classical antiquity, with the Indian ocean, opening up new roads for world trade.[6] It inaugurated a thousand-year era during which all the major civilizations of Eurasia, the Greek, Roman and Sanskrit traditions, but also Irano-Semitic and Malay-Javenese cultures, were brought into contact with each other. In the course of this process, elements from these traditions were integrated into an overarching cultural framework that survived even long after the decline of centralized political authority, a topic to which we return (Eaton 1993, 12).

The spread of knowledge induced by the spread of political power is exemplified by technologies such as agriculture, ceramics, textile fabrication and metallurgy, and of cultural techniques such as writing, accounting, monetary economy, mathematics, architecture, artistic representations, astronomy and calendar systems. For instance, mathematical puzzles, as part of sub-scientific mathematics, may have migrated across the Eurasian continent during campfire and tavern conversations among merchants and military men (Høyrup 1989). Such diffusion processes significantly contributed to the accumulation of a potential which later became significant for the emergence and diffusion of science. Remarkably, this accumulation reached beyond the eras of single empires, since their succession usually involved, even when major destruction took place, the adoption of parts of pre-existing infrastructure, the inclusion of at least some members of the intellectual elite and a continuity of local technological or cultural achievements. As a result, the historical succession of large empires from the Mesopotamian, via the Roman and the Persian empires to the Islamic Empire comprised significant global learning processes. For example, Roman regulations for agriculture found their way into the corpus of Islamic law; Persian economic achievements played the role of a model employed by the Arabs in their conquests (Glick 2005, 6–7).

This is not to say that major breaks did not occur in transitions from empire to empire, such as the disappearance of wheeled vehicles in the Islamic world, which was due to the invention of the rigid north-Arabian camel saddle (Bulliet 1977). A key example for the long-term accumulation for the potential of science

[6] See (Glick 2005, 3, fn.1) and the references therein. For the coupling of monetary economies between Europe and the Muslim world between 1000 and 1500 CE, see also (Watson 1967). For the relation between the Islamic world and Tibet, see (Akasoy et al. 2011).

is the invention and dissemination of paper as a cheap writing material.[7] It thus took on a role that was played in antiquity by clay and papyrus, which also helped to spread literacy, in contrast to the limited literacy in medieval Europe, partially caused by the reliance upon parchment and skins for writing materials. Paper making was known by the second century CE in the Han Dynasty in China and then traveled to Eastern and Western Asia, following the Silk Route. By the end of the seventh century, paper making had reached the Indian subcontinent, and by the middle of the eighth century Samarkand, transmitted by Chinese prisoners to the Abbasid conquerers. Subsequently it spread to the rest of the Islamic world.

The diffusion of paper illustrates the layered structure of globalization processes and the associated retardation effects discussed in chapter 1. Paper began to spread from China only after it became widely used. It was first introduced to other areas as a commodity and only much later reproduced by local technology. Thus paper was known to the Arabs by the seventh century, while the technology for manufacturing it arrived more than a century later. By the tenth century, paper had entirely replaced the use of papyrus. Similarly, it was known in Europe no later than the tenth century, while paper mills were constructed only about two centuries after its initial introduction. It took another century before Europeans realized that the Chinese also used paper and much longer before they became aware that it was actually their invention. The extent to which the connectivity provided by the Islamic Empire accelerated the spread of technological inventions by the Chinese is remarkable when compared to their spread before the rise of this empire (Glick 2005, 247–248). This is also true of another key example for the gradual accumulation of potential for the globalization of science: the invention of the Indo-Arabic numeral system, now in universal use.

The oldest numbers written in this place-value system with base 10 are found on the Gujarat copperplate inscriptions from about 595 CE. There is, however, textual evidence that the place-value system originated much earlier. At least since the mid-third century, a concrete number system was used in India that associates numbers with concrete or religious objects and arranges them in a place-value system. Remarkably, one of the earliest texts testifying to the use of this system is an astrological treatise based on a Greco-Babylonian astrological tradition. The Indian place-value system may thus have roots in the Babylonian tradition, but it may also go back to the use of counting boards with an intrinsic decimal place-value structure as they were used in China, from which they may have been brought by Buddhist pilgrims. While the autonomous development of the system in India cannot be excluded, its emergence from transmission and transformation processes of older knowledge brought into new contexts and represented by new media is not entirely unlikely. One new medium were Indian literary texts which made use of the above-mentioned concrete number system for reasons of style and required synonyms for ordinary number words so that the scansion of a verse would not

[7] On the history of paper, see (Tsien 1987). For its diffusion to Europe, see also (Glick 2005, 279–281) and (Burns 1985).

be ruined. Such literary contexts may have hence preceded the use of the new number system for calculation.[8]

By the seventh century, the decimal place-value system had reached Syria in the West and Cambodia, Sumatra and Java in the East. By the late eighth century, the Indo-Arabic numerals were known in the Islamic Empire. In 773 CE, a group of ambassadors from India visited Baghdad, including a scholar with astronomical and mathematical expertise. One of the first authors of mathematical treatises in Arabic was Al-Khwarizmi, from Chorasmia, who worked in the first half of the ninth century under Calif Al-Mamun in Baghdad at the House of Wisdom. His arithmetical treatise is the first known Arabic work using the Indian decimal-place system. While Indian numerals became known in the West as early as the late tenth century, it was the Latin translation of this treatise that caused them to be widely adopted in Western Europe. In the first half of the thirteenth century, easily accessible introductions to calculating with the new number system were written that became adopted as textbooks in the newly founded universities and grammar schools. They also became the basis for the widely spread mathematical training in vernacular languages (Folkerts 2001). Without the globalization of paper and Indo-Arabic numerals, the worldwide success of early modern science would have been unthinkable.

9.3 The Role of Empires and the Fragility of Higher-Order Knowledge

In the great empires of pre-colonial times, the production and dissemination of higher-order knowledge, as represented by political, religious, juridical, literary or scientific writings, depended largely on institutional structures with varying degrees of fragility and with strong dependence not just on the political and military fortunes, but also on the ideological preferences of their rulers. This changed in colonial times when such knowledge became an essential instrument for domination. More generally speaking, the transmission of higher-order knowledge depends on the existence, social status and social reproduction, as well as on the demographic size, of an intellectual elite concerned with such knowledge.[9]

The idea of an empire presents itself as a form of second-order knowledge, as may be illustrated by the fact that this idea traveled and was also emulated by populations for which this form of political organization was new. Examples are the rural and nomadic populations surrounding the Roman and the Chinese empires which eventually created similar political structures shaped by knowledge taken from the empires with which they struggled.[10] In the Chinese state bureaucracy, certain forms of moral, administrative and political knowledge were

[8] On the history of the Indo-Arabic numeral system, see (Plofker 2009, 43–48). See also (Kunitzsch 2003).

[9] Cf. the discussion in (Glick 2005).

[10] For the Roman case, see, for example, (Heather 2006); for the Chinese case, see, for example, (Barfield 2001).

transmitted over long periods of time, even across dynastic changes. As we saw in chapter 3, the Babylonian tradition of astronomical observations also survived major political upheavals. The fate of Greek and Hellenistic philosophical and scientific traditions was closely associated with the changing political support for their institutions, such as the Academy in Athens or the Museion in Alexandria, which were repeatedly endangered by ideological and military threats.

Also in the Islamic Empire, the cultivation of secular intellectual activities relied mainly on courtly patronage, in particular that of the Abbasid caliphs from the ninth to the thirteenth century.[11] The Greek-Arabic translation movement began in the second half of the eighth century in Baghdad and lasted at least until the end of the tenth century. It took place in a multicultural and multilingual environment, involving speakers of Greek, Syriac, Persian (Pahlavi), Arabic and Hebrew with translations from Greek into Arabic often passing through intermediate languages. It enjoyed the patronage of the Abbasid Dynasty and initially mainly served legitimatory purposes, creating an intellectual continuity with the great empires of antiquity and maintaining the cohesion with the various influential ethnic and cultural factions comprising the elite of the new society in Baghdad. Political and ideological motivations thus favored a continuity of learning, which was anything but self-evident in view of the major societal disruptions of that time. According to Gutas, a central background was provided by the Zoroastrian imperial ideology of the Sasanian Empire conquered by the Arabs, and was adopted by the Abbasid rulers after they transfered the seat of the caliphate to Baghdad. This ideology was still shared by a significant part of the Persian-speaking population, even after the Arab conquest. It was used by the second caliph and builder of Bagdad, Al Mansur, in the second half of the eighth century as a means to co-opt the local elite and integrate them into the new Abbasid state. The Zoroastrian imperial ideology comprised the belief that all sciences originally derive from the Zoroastrian canon, but had been appropriated by the Greeks in the course of Alexander's conquest of Iran, so that their translation into Persian (Pahlavi) was simply a recovery of the Zoroastrian heritage. The cultivation of translation activities was hence an integral part of this ideology and as such also taken over by the Abbassidian rulers. The Zoroastrian imperial ideology may be considered second-order knowledge preserving an awareness of epistemic continuity in the Middle East. The institutionalization of this knowledge for political reasons in the early Abbasid Dynasty made it instrumental in the recovery and transformation of ancient knowledge traditions through the creation of a state-supported translation movement.

The new knowledge thus generated and widely shared in the extensive Islamic state of the Abbassids then became itself an important aspect in the societal development. In particular, the acquisition of further knowledge became more de-

[11] See chapters 12 and 13, the classic paper by Benz (1961), the masterful survey by Dimitri Gutas (1998), as well as the introduction in (Abattouy et al. 2001a)—co-written by the author—on which much of the following is based.

termined, not only by the ideology that had originally motivated the translation movement, but also by intrinsic motives related to the nature of this knowledge. Although initially astronomical knowledge was mainly sought for political motivations related to the legitimatory role of astrology for the new dynasty, its acquisition increasingly became a matter of intrinsic scientific interest. Early translations tended to be connected to the practical context they purported to serve. This context was often defined by the institutional frame that supported and financed the translation work. The translation of medical texts was fostered also by hospitals, which were institutions not just of caregiving but of study as well. Greek medical knowledge competed with Indian medical knowledge that was also translated into Arabic (Dols 1987). Eventually, translation activities were more and more guided by the intrinsic development of "naturalized" Muslim sciences, institutionalized in the form of curriculae and sets of equipment and instruments that defined their further development (Sabra 1987). At the same time, the Greek-Arabic translation movement was a powerful transmission mechanism, preserving Greek scientific material, often in a form superior to the Greek texts that were simply copied within the Byzantine tradition, with its less-developed scientific culture (Lorch 2001).

In the Arabic-Latin translation process, this transmission and transformation was continued. Remarkably, it was shaped not only by local motives, but also by global political constellations.[12] Centers of transmission from Arabic into Latin typically emerged at the boundaries of the Catholic world with regard to the Islamic and Byzantine Empires and in areas that were multicultural and multilingual, such as Spain and southern Italy, particularly in Sicily.[13] A further condition favorable to the transmission of knowledge across cultural borders was the existence of boundary spaces with comparatively high political and religious tolerance. A prime example was Toledo, reconquered without bloodshed from the Arabs in 1085. In contrast to the territories controlled by the repressive regime of the Almohads in North Africa and parts of Spain, Toledo offered room for contacts and cross-cultural collaborations.[14] It thus became pre-eminent for the translation of philosophical as well as scientific texts in the Aristotelian tradition.[15] The emphasis on specific types of knowledge transmitted depended on local circumstances and interests. A real translation movement therefore did not begin before the mid-twelfth century—Gerard of Cremona being one of the leading figures—since before this time an audience interested in translations from the Arabic was scant. In 1140, an important Arabic library became available to the Christian rulers with a wealth of books on mathematics, astronomy, astrology and magic, from which Gerard probably took some of his sources. As in the case of the Greek-Arabic translation movement, translations were often performed using intermediate lan-

[12] For discussion, see (Gutas 2006), in particular p. 18.

[13] See the discussion in (Burnett 2001) on which much of the following is based. See also (Schramm 2001) and (Hasse 2006). For a more general discussion of the translation movements in Europe and the Near East, see (Kunitzsch 2008).

[14] See (Endreß 2004).

[15] See (Schmidt 1957), (Benz 1961, 147–165).

guages, in particular the vernacular, as well as in collaboration with Jews and Arabized Christians. For example, Avicenna's book on the soul was translated from the Arabic via the vernacular into Latin by the Jewish scholar Abrahim Ibn Daud, who had emigrated from the Almohad territories together with the archdeacon Domenicus Gundissalinus. As in the Greek-Arabic movement, patronage also played a key role, here by the Cathedral, especially by the Frankish archbishop of Toledo.

In Salerno, not far from the Byzantine settlements in Puglia, Greek texts on medicine began to be translated into Latin from the eleventh century on; in the twelfth century, Palermo, on the outskirts of Europe, became a meeting point for Latin and Arabic scholars who generated translations as well as new joint contributions. In the twelfth and thirteeth centuries, a network of scholarly migrations began to develop between these centers at the boundaries, and now also included urban centers which sustained scholarship in the heart of Europe, such as Oxford and Paris. The Arabic-Latin translation movement cannot be understood from a merely local perspective. It was the emergence of a European market for its products and the growth of the scholarly network and its institutionalization that fostered translation activities beyond the motives of their local inception.[16] Furthermore, the varying ways in which different cultures interacted depended on the local manifestations of conflicts of geopolitical dimensions. These ranged from courtly encounters between Catholics, Byzantine Christians and Muslims in Palermo, to the appropriation of the scholarly and technological achievements of a besieged enemy after the "Reconquista" of Toledo. Like the Greek-Arabic translation movement, the Arabic-Latin translation movement did not just involve the transmission of texts: it developed from a clash between two worlds, both of which embodied universal claims to political and ideological dominance. For Latin scholars, this resulted in an opportunity to encounter an active scientific culture previously almost inaccessible to them.[17]

Until the early modern era, the globalization of articulated higher-order knowledge such as philosophical and scientific knowledge expressed in writings was a haphazard process. Such higher-order knowledge was typically not embodied in stable social and administrative structures. It involved chance encounters, often fragile institutions, intellectual syntheses achieved by outstanding individuals, or schools such as those of Plato and Aristotle in ancient Greece or the Mohist school in ancient China, and the more or less fortunate transmission of their knowledge preserved in writing. But practical inventions, such as paper making, and the

[16]The scholarly network induced by the translation movement comprised hubs with different functions, translation centers, such as Toledo, centers of learning and dissemination, such as Paris and Oxford, and depositories of knowledge, such as the Monastery of Saint-Michel. The recent controversy about the origins of western Aristotelianism, launched by Sylvain Gouguenheim (2008), has helped to make the distinction between the functions of these different centers clear. See the afterword in (Gouguenheim 2011).

[17]Alfonso the Tenth (1252–84) concentrated the translation activities that had been scattered around Spain in one location and subdivided and organized the labors of his translators.

transformations and globalization of such higher-order knowledge in successive historical phases created some of the crucial preconditions for the emergence and spread of modern science.

The transformation of Greek science and philosophy in the Islamic world, for instance, and its transmission to the medieval Latin world, constituted a critical mass of knowledge with a shifted focus—when compared to late antiquity—and with far-reaching consequences. One example is the transformation of the ancient tradition of mechanics, dealing with a variety of mechanical instruments, into a "science of weights" focusing on the balance and giving rise to new mechanical concepts.[18] Another example is the prominence acquired by Aristotelianism and the original contributions to it in the Islamic world.[19] The circulation and appropriation of this knowledge in the West eventually helped trigger the emergence and spread of universities, as well as the formation of the scholastic worldview that later served as the matrix for the birth of modern science. In this sense, modern science was more an outcome of the globalization of ancient knowledge rather than its renaissance.

We mentioned above that the large-scale sociopolitical structures of empires fostered the travel of knowledge, in particular when it was deemed politically, ideologically or economically relevant. The thirteenth-century CE Mongol Empire, for instance, created an interaction sphere ranging from Central Europe to East Asia, effecting a horizon for thought and action that extended throughout Eurasia. It enabled the encounter of knowledge traditions that were hitherto largely separate from each other, such as the Hellenistic-Islamic and the Chinese astronomical traditions. However in this case, astronomical knowledge remained merely a useful commodity produced in an almost artisanal way; it was spread by the migration of experts or by the copying of calculational techniques (van Dalen 2002). Knowledge and personnel were exchanged, but the different intellectual traditions were not integrated into a larger system of knowledge—in contrast to what happened in late antiquity to Babylonian and Greek astronomical knowledge in the work of Ptolemy. Nevertheless, large empires such as the Mongol Empire not only created favorable conditions for long-distance traveling, but also an awareness of global political and religious constellations that offered global perspectives of intervention, even to figures not directly involved in political matters, such as merchants, missionaries, adventurers and even intellectuals. A prominent example is Marco Polo, a merchant from the Venetian Republic who served the Great Khan as a diplomat and whose travel account later inspired Christopher Columbus to search for the sea route to India after the land passage to India and China became increasingly difficult following the fall of Constantinople to the Ottoman Turks in 1453.[20]

[18] See (Abattouy et al. 2001a) and (Renn and Damerow 2012).

[19] For a standard reference, see (Pines 1979).

[20] On the voyages of Marco Polo, see (Larner 1999). On visits to Europe from Asia, see (Rossabi 2010).

In the age of European colonization from ca. 1500, the production and dissemination of knowledge, and in particular of higher-order knowledge, assumed a new and much more significant role. Its role was determined primarily, at least initially, by the function of knowledge in the colonizing societies. After the early modern age, scientific and technological knowledge in some European societies started to become more central to economic production, social organization and political regulations, as well as to the self-image of the leading classes, a process that eventually led to an industrialization involving scientific knowledge to an ever greater extent.[21] The very possibility of colonization depended on this process, which involved the production of improved ships, maps and navigational techniques, developed weaponry and sophisticated logistics, as well as the capacity to absorb knowledge from the colonized and the creation of knowledge production centers in the colonies. This is not to claim that Europeans necessarily possessed technology superior to that of other cultures. Consider, for instance, the superb equipment and navigational competence available to the Chinese in the early fifteenth century. What characterized early-modern European societies is rather the historically contingent social, political and military dynamics in systematically exploiting and enhancing their technological potential for colonial conquests.[22] The background knowledge enabling such achievements was produced and disseminated by institutions with greater social penetration and stability than ever before, not only schools, universities, guilds, archives or academies, but more generally all forms of the institutionalized transmission of practical knowledge relevant for commercial and military purposes.[23] It was the onset of a self-accelerating process that necessarily involved even those territories exposed to colonial domination and expropriation in Asia, Africa and the Americas.

European colonial endeavors also relied on earlier phases of the globalization of knowledge, from the exchange of innovations across Eurasia since the beginning of sedentariness to the awareness of the geopolitical situation after the Fall of Constantinople, which effectively blocked earlier connections between the two ends of Eurasia. If, however, only the role of these earlier globalization processes is emphasized, and, in particular, their facilitation by the East-West connectivity of

[21]For a discussion of the social and economic roots of the Scientific Revolution, see, for instance, (Lefèvre 1978; Freudenthal and McLaughlin 2009; Damerow and Renn 2010) and the older literature cited there.

[22]For Chinese seafare in the fifteenth century, see (Ptak 2007). Older literature often claims a general superiority of European cultural techniques, see, for example, (Konetzke 1964). Newer literature tends to underline the cultural contingency and the very special use Europeans made of these techniques, see (Gruzinski 2011). For information on shipbuilding, map-making and other conditions of European seafare related to the production of new knowledge, see (Harley and Woodward 1987, 410; Russell-Wood 1998, 27–31; Renn and Valleriani 2001; Padrón 2002; Kamen 2003, 159–160; Nowacki and Lefèvre 2009).

[23]The case of archives is discussed by Nicholas B. Dirks (2001) who stresses the role of archives as neutral repositories of the past, focusing on colonial Imperial British India. Ann Laura Stoler (2009) goes further when she considers archives and archival documents not only as sources, but also as having histories and itineraries of their own.

Eurasia as a primary reason for the superiority of European colonial powers over indigenous populations of Africa and America (Diamond 1998), one risks underestimating the significance of the early modern knowledge economy for colonialism and, in particular, for its sustainability beyond the first conquest. The crucial role of the link between epistemic and economic processes in this period, to which we return in the next section, also becomes visible in the different degrees to which European competitors such as Spain, England and the Ottoman Empire became successfully—from their perspective—enganged in colonial enterprises.

Non-European territories and their societies offered, on the one hand, new resources for the knowledge economy of the colonizing societies, such as new biological specimens potentially relevant for agriculture or medicine.[24] On the other hand, their domination required the extension of this knowledge economy beyond its original borders to also include those colonized societies with different cultural and epistemic traditions (Crosby 1972, 64–121). Historically, these extensions took place along radically different lines. Nevertheless, several features are common to all alternatives: the destruction or decline of local institutions concerned with the production and dissemination of knowledge; more or less successful attempts to transplant institutions of higher learning from the colonizing to the colonized societies; attempts to legitimize the transferred scientific and technical knowledge by naturalization, that is, by establishing links to indigenous epistemic traditions; the eventual integration of at least some aspects of local knowledge that turned out to be better adapted to local circumstances than globalized knowledge; and, more generally, the transformation of the dominated territories into sites of often ruthless political, social, technical and scientific experimentation. In addition, there are many cases where medical or agricultural knowledge, for instance, would have been adaptable and yet was suppressed by the colonized subjects at least as much as by the colonizing powers.

9.4 The Role of Religion and the Endurance of Higher-Order Knowledge

The power of empires never comprised just military, political and economic dominance. It was based as well on the support of belief systems that regulated social order beyond the exertion of crude force. Political and religious control was accordingly exerted by overlapping social hierarchies of rulers and priests. Religions are social systems constituting collective identities.[25] One of their means for doing so is knowledge and, in particular, second-order knowledge, prescribing the role of knowledge in the given collective identity. Shared societal belief systems have their origin in the religious practices of tribal societies as a medium of social

[24] There is a very large literature on this theme. See, for example, (Arnold 1988; Grove 1995; Müller-Wille 1997).

[25] See (Durkheim 1965; Heinrich 1986; Simmel 1995). On the transmission of social hierarchies, see also (Lincoln 2007).

self-awareness. Later, these belief systems reflected the rising social complexity of urban and state societies, and this development was accompanied by an increased social differentiation of political and religious elites. The potential range of belief systems in space and time was considerably enhanced when the medium of writing was employed for their representation. In the third millennium BCE, religious beliefs and practices were among the first subjects of written documentation outside the original use of writing for administrative purposes.[26] In this way, belief systems, as well as the corresponding literary works, practices or religious ideas, such as that of an original flood, documented in the Babyloninan Epic of Gilgamesh, could travel well beyond the spatial and temporal confines of the societal setting in which they originally emerged.[27]

Religious practices include initiation and sacrifices, prayers and other ceremonies, often timed according to astronomical events, but also institutionalized education, building activities, artistic and literary productions. Because of the close association between religious practices, teachings and institutions, such comprehensive belief systems tend to generate packages of knowledge, that is, conglomerations of diverse components pertaining to linguistic and philological knowledge, social and psychological knowledge, or practical knowledge of the arts. These packages may thus have been rather heterogenous, but at the same time they constituted relatively stable units in transmission processes. There is, moreover, one characteristic organizing principle to this bundle of knowledge: it is assembled to provide answers to questions that are unavoidably generated by the knowledge about the world with regard to the position of the individual, the group, or the society in this world. Questions could include: where do I come from and where do I go from here, what can I hope for and what can I believe in? These questions are an unavoidable consequence of the self-reflexive, self-organizing character of knowledge.[28] As individuals we cannot avoid thinking about them, while religious and other belief systems provide collectively sanctioned answers to them. Such answers are, however, highly mediated by institutional frameworks, by traditionally accepted external representations, by procedures of appropriation that may or may not achieve their goal of mediating between individual and social self-awareness.

Religious transmission processes involved, for instance, the dissemination of holy writings and their interpretations and thus fostered the spread of key cultural techniques, such as writing, translating and calculating, but also the transmission of educational processes closely related to initiation rites (Assmann 1992). Religions thus developed early, including many of the features that were later characteristic of science: educational institutions such as monasteries and madrasas

[26]In the Early Dynastic period, so-called "god lists" emerged, primarily serving administrative purposes, i.e., teaching how one writes the name of a particular god in an administrative document. The next group of written texts that emerged after administrative documents were primarily legal.

[27]See (Maul 1999; George 2003; Foster et al. 2001). For the transmission into Hittite and Hurrian, see (Salvini 1988; Beckman 2003).

[28]For the character of religious knowledge, see also (Freundenthal 2012).

(schools of higher learning), recursive traditions of interpretation, commenting, confrontation and integration with other belief systems, and a systematization of knowledge that included control structures for its legitimacy. Also in the religious context, this breadth of knowledge, often accumulated over centuries, nevertheless remained but a fellow traveler, even if an unavoidable one. The pursuit of religion was, after all, guided by motives other than the exploration and reflection on the knowledge assembled in those packages, which instead remained a mere by-product, and sometimes an undesired one.

The long-term effects of the spread of knowledge fostered by large empires was possibly surpassed by those in the wake of the world religions. At some point in their development, these may have been or may have become state religions, such as Buddhism in Northern India under King Aśoka, Christianity in the late Roman Empire and Islam under Mohammed and his followers in the Arabic world. Under these conditions they incorporated (or helped to create, as in the case of Islam) many of the institutional and representational structures of an empire state, such as differentiated social hierarchies, a more or less comprehensive worldview, and institutional mechanisms for its preservation and transmission. The self-contained and self-organizing quality of some of these state religions rendered them capable of challenging the authority of the political powers and of far outlasting their initial reference states. In ancient Judaism, for instance, the authority of the state, as well as of the state religion represented by the priests, was challenged by the prophets. Later, after the destruction of the Second Temple and the Jewish state, religious and community rule became one, with an emphasis on religious knowledge (Goodman 1998; Kalmin 2006).

Indeed, world religions could become attractive belief systems to be adopted by states and empires seeking to regulate their social order, precisely because of their self-consistent quality. As a consequence, the world religions fostered an even wider spread of knowledge and had an often more durable nature than that of the expanding empires.[29] To some extent, world religions may be considered virtual empires that share their superstructure, but not necessarily their economic basis. This is not to say that the spread of world religions was not significantly propelled by military and economic conquests.

Such all-encompassing belief systems, as world religions offer, as mentioned above, a powerful medium for articulating individual and social self-awareness and self-reflection, and in particular for their mutual interaction. They not only incorporate knowledge about social and psychological mechanisms, but also make it possible to further develop this knowledge within their representational and institutional structures. As a means for generating self-awareness and hence for reflectively constituting individual and social identity, they also impose a second-order epistemic framework that guides the selection, appropriation and agglomeration of new knowledge by determining the value of knowledge for the individual

[29]See (Bayly 2004, chap. 9) on empires of religion. See also Tyrell (2004) who investigates how German and British mission organizations contributed to globalized world religions.

and collective self (Schleiermacher 1912). This may happen in widely differing ways and may also change over time. Nevertheless, due to their social penetration and high degree of reflexivity, religious systems tend to have a greater stability than most systems of knowledge, for which they may serve as a complementary embedding providing meaning and reflexivity that these knowledge systems do not. Buddhism, for example, has developed a deconstructive epistemology largely immune to historical developments of knowledge.[30] The normative dimension of Islam is, just as is the case for Judaism, not confined to certain areas of religious practice, but extends to all dimensions of life and hence also to the evaluation of all forms of knowledge.[31]

Religious systems, comprising both an overarching second-order epistemic framework and distinct packages of knowledge, are continuously challenged by new knowledge. In the case of medieval Christianity, the integration of knowledge newly acquired through the transmission from the Islamic world led to a belief system that increasingly functioned as a universal system of knowledge and thus also became increasingly sensitive to such epistemic challenges. This system of knowledge received institutional support from the newly founded universities.[32] The Christian-scholastic philosophy, based on Aristotelian philosophy, connected the previously mentioned theological statements with rather concise statements concerning the constitution of the world. From the thirteenth century, a synthesis of the religious worldview and the available scientific knowledge emerged.[33] This highly differentiated system of knowledge was prone to the challenge which naturally accompanies the acquirement of new knowledge. The Christian scholastic system of knowledge was thus exposed to a constant process of transformation, but because of the primacy of religion dominating the dynamics of knowledge it was, at the same time, subject to externally imposed limitations. This situation helps to explain why in the sixteenth century the reform of astronomy by Copernicus, placing the sun rather than the earth at the center of the universe, could have had such far-reaching ideologic consequences: it occurred within the context of a socially dominant system of knowledge which claimed to be universal and exclusive. The impact of the Copernican Revolution on astronomical knowledge in Europe—and ultimately the European Enlightenment—would be unthinkable without the preceding epistemic transformation of Christianity.

A similar transformation of the neo-Confucian state religion dominating classical China evidently did not take place, not even in the early modern period when the Jesuits introduced the knowledge of European science on a broad scale in the

[30] See section 10.4 of chapter 10.

[31] See chapter 12, in particular section 12.1.

[32] See (Rüegg 1996a,b). The role of the universities for shaping a scientific agenda has also been stressed in (Huff 2011, 147–52). The author points to the role of the legal transformation in the twelfth and thirteenth centuries which opened up the possibility of a legal status for collective actors, such as corporations and universities, claiming this as a distinctive European development.

[33] For an overview, see, for example, (Lindberg 2008).

form of books and private and institutionalized instruction.[34] Instead the new knowledge, in particular that about calendar making and the prediction of astronomical events, was selectively assimilated to the Chinese system of knowledge. Unlike the complex of Christianity and Western science, this was not decoupled from the state to the extent that it constituted a worldview with a legitimization independent of the authority of the state. Instead, it derived its ultimate justification not from an epistemic framework, but from its constitutive role for the state. Hence, the Chinese system of knowledge could not be challenged in the same way as its Western counterpart by the accumulation of new knowledge.

In the European case, the capability of religion to challenge the authority of the state in terms of its own, internal logic eventually favored that of science to challenge the authority of religion. In early modern times, the potential of science to undermine the dominant structures of knowledge relating to religious views of the world had been reinforced by the increasingly real or anticipated practical and economic significance of science, in particular by the practical challenges for science in dealing with the large engineering endeavors of the times. The artisanal practice at the Arsenal of Venice or large building projects like the cathedral of Florence, for example, were dependent on innovative knowledge from all over the world. This practical significance of science also accounted for the development of a new image of knowledge. In answer to the dominant religious worldview, this image of knowledge started to assume the character of an all-embracing interpretation of the world, as it is found in the great philosophical concepts of early modern times, for instance in the works of Giordano Bruno or René Descartes. Science eventually became a kind of counter-ideology by which the emerging bourgeoisie could defend its claims of ruling the world, not according to a transcendent, religious order, but according to its own immanent laws.[35]

The new role of science in the West became relevant at a time when its links to the religious worldview were eroding because that worldview was challenged by the growing mass and complexity of the rapidly accumulating knowledge. This knowledge explosion counteracted all attempts to confine the expansion of knowledge and eventually helped to foster the creation of an institutional basis for science, independent of its role as a fellow traveler. In this historical situation, a self-reinforcing mechanism emerged that connected the production of scientific knowledge with socioeconomic growth. We come back to this mechanism in chapter 24. From that point on, the economy of knowledge was no longer merely a by-product of other societal processes, a fellow traveler of political, military and economic developments, but had transformed into an essential motor of this process. This development occurred in Europe but was the result of a long-ranging process of globalization of knowledge and involved the refraction of knowledge traditions across several cultural breaks, for example, from Mesopotamia to Greece,

[34] See chapter 11, in particular sections 11.1 and 11.5.

[35] For this interpretation of the Scientific Revolution, see (Lefèvre 1978; Renn and Valleriani 2001; Damerow and Renn 2010).

from Greece to the Arab world and from there to Latin Europe, as key processes of intellectual innovation. Such refractions of knowledge traditions were associated with changes in perspective and made the endeavor of modern science possible in the first place, as well as the resonance between scientific and socioeconomic globalization.

The extent to which such self-reinforcing simultaneity of scientific advances, the possibility of exploiting science for ideological purposes and a growing practical role for science also took place in the Islamic world is still an open question.[36] Further studies are needed to identify the historical opportunities—whether missed or realized—for extending the flourishing of science as a fellow traveler in the age of large Islamic empires and tolerant religious practices to an economically viable regime that favored the development of an autonomous institutional basis for science.

While knowledge as a fellow traveler of religion tends to form heterogeneous and often rather accidental packages held together by tradition and transcendent legitimacy, an autonomous societal basis for the generation and transmission of knowledge fosters the creation of systems of knowledge held together by internal coherence and intrinsic legitimacy. We thus see, once more, the self-organizing quality of knowledge systems and their transmission. The previously mentioned scholastic Aristotelianism of the Middle Ages, for example, formed such a system of knowledge with its own institutional basis and self-referential argumentative structure. While it did receive a transcendent legitimacy from its embedding in Christian theology, its own intrinsic logic was strong enough to conflict with theological assumptions and to play a generative role for the emergence of early modern science.

9.5 Science as a Fellow Traveler

Science itself, on the other hand, may act much like a religious tradition when it is transferred to a society with an epistemic framework and an institutional basis for the assimilation, production and transmission of knowledge that is different from that of the society from which science has been transferred.[37] What is being transferred under these circumstances are thus packages and not systems of knowledge. Their structure depends less on the constitution of the original system and more on the patterns of appropriation and accommodation in the target society.[38] What seemed a systemic necessity, for example, in the sequence of arguments in the context of origin, may in the new context emerge as an accidental constellation of distinct elements of knowledge, offering the option of changing their relation to each other, dropping some of them altogether, or adding others.

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[36] See the discussion in chapter 13.

[37] For a discussion of the intercultural aspects of scientific exchange, see also (Aoyama and Seebold 2005).

[38] See chapter 14, section 14.5.

In consequence, one typically finds, if not just selective assimilation of new knowledge within a preexisting local system of knowledge, a remixing of the components of imported science with components of local knowledge.[39] Such a repackaging of scientific knowledge is typical of the transmission of science as a fellow traveler of religious mission, as in the case of the Jesuit mission to China in the sixteenth and seventeenth centuries, of the spread of science to the European periphery in the eighteenth and nineteenth centuries, and of colonization in the nineteenth and twentieth centuries.[40]

Science may evidently also act like a belief system in another sense: by shaping the identity of its protagonists. When science spreads as a fellow traveler of religion, its practitioners almost unavoidably adhere to different and overlapping belief systems. Conflicts of identity are thus the rule rather than the exception and may drive further development.[41] More generally, the globalization of knowledge always leads to a differentiation, both on the level of knowledge itself and on that of the identity of its protagonists. As a consequence, knowledge as a fellow traveler never remains a neutral commodity with regard to its means of transport, its sources and its recipients. Due to its self-referential qualities (the reflection of knowledge generates new knowledge), it may rather induce, under appropriate circumstances, systemic changes that tend ultimately to overcome its subordinate role as a fellow traveler. Thus the production and dissemination of scientific knowledge as a fellow traveler of colonization, could, by an active accommodation to new circumstances, also become a powerful motor of decolonization, as the example of twentieth-century India illustrates.[42] However, as long as the development of scientific knowledge remains isolated from that of knowledge at large, its transformative power, and in particular its impact on the dominant epistemic constellation, is limited. But, as we have stressed, the boundaries between first and second-order knowledge are always shifting, with the effect that any process of knowledge generation may acquire a subversive power undermining, at least in the long run, the dominant constellation.

[39]See the discussion of *métissage* in the colonial context as a form of communication wherein no "veritable fusion" of European and autochthonous knowledge took place, but quite selective and short-term practices of mixing *métissage* and unmixing *demétissage* of knowledge prevail (Lienhard 1999, 60–61). According to Ann Laura Stoler (2009, 249), knowledge in the colonial context was generally unstable. See also the discussion in the survey chapter 16.

[40]See chapters 11, 14 and 15.

[41]Such conflicts of identity are at the heart of conversion processes, as explained in (Viswanathan 1998, 75): "I propose examining conversion as an act akin to the forces of modernity in its appeal to personal (rather than collective) choice, will, and action; to the forces of colonialism in its introduction of other epistemologies, ideologies, and cultural frameworks; and to the forces of feminism in its representation of subjectivity at variance with what is legislated not only in code books of social morality but also in civil and ritual practices. Combining the effects of all three, conversion posits a severe challenge to the demarcation of identities set by the laws that govern everyday life and practice. Changes of religious belief reconstitute the shape of the nation just as forcefully as do systems of personal and customary laws, which lay the groundwork for organizing different communities along sectional lines."

[42]See chapter 15.

9.6 The Nature of Religious Knowledge

When knowledge is transmitted as a fellow traveler, its distributivity, that is, the extent to which it is shared, is governed by the medium with which it travels, be it the expansion of an empire or the spread of a religion. As the transmission of knowledge is determined by such extrinsic dimensions, these also govern its reflexivity and systematicity. Religious knowledge in particular comes, as discussed in section 9.4, in packages comprising various kinds of practical and theoretical knowledge which, however, are not necessarily strongly interrelated so that the systematicity of this knowledge is low. Religious knowledge may comprise artisanal knowledge about certain building techniques, but also theoretical knowledge which, however, does not typically relate to this kind of practical knowledge.

Buddhism, for instance, comprises techniques and styles of visual representation and of architecture that spread widely across Asia.[43] Within the monastic communities of Buddhism, social knowledge was cultivated that could be exploited under appropriate circumstances for political purposes. But the main component of religious knowledge is shared higher-order knowledge resulting from a reflection on a broad range of collective human experiences from birth to death, from love to war, from success to failure, from anxiety to joy. Religious knowledge comprises interpretative schemes that make these experiences "meaningful," typically in the sense of helping to reestablish the coherence of self or of a community in the face of challenges threatening to tear them apart. It often also comprises, however, reflections on a broad range of experiences with the working or failure of these very interpretative schemes. To which extent religious knowledge is, at its core, meta-knowledge is best illustrated by the Buddhist insight into the fragile nature of all such attempts to preserve the self, developed in opposition to Brahmanical philosophy which believes in an eternal self and equally eternal social structures.

Because of the essential role of meta-knowledge in religions, they provide second-order epistemic frameworks determining the place for other types of knowledge, with differing potentials for these other knowledge components to influence these epistemic frameworks in turn. More generally, the dynamics of knowledge production and dissemination is shaped by dominant epistemic constellations, also determined by political, economic and cultural boundary conditions mutually interacting with each other. Religions are often only one, albeit often crucial, element of these constellations. In Ming China, for instance, morality was the domain of the state, while religion was a private matter supposedly having nothing to do with the state.[44] When knowledge contained in a package with religion turned out to be relevant for the state, the natural reaction was to disentangle it from its religious context. In medieval Christian Europe, religion shaped morality and interfered with the state, but was nevertheless independent of it and could even oppose the state. Accordingly, this was also the case for knowledge packaged with

[43] See chapter 10.
[44] See chapter 11.

religion. In Islam, the ideal community of original believers sets normative standards for all dimensions of human behavior and the Koran is considered to be a holy book not comparable to other books, and hence beyond the realm of critical interpretation in terms of human knowledge production. While there was room in Islam for associating further knowledge with this epistemic core, it was apparently more difficult to challenge it.[45] Such epistemic constellations also operate on smaller, historically more specific scales: Greek-speaking Orthodox Christians in the Ottoman Empire developed an intellectual identity distinct from the Muslim East and the Catholic West. This identity expressed itself in the development of a neo-Aristotelian philosophy governing their appropriation of new scientific knowledge from the West.[46]

In accordance with the epistemic framework given by the dominant constellation, or more specifically, a particular religion, different types of knowledge are produced, transmitted and associated with each other, often according to an explicit classification of knowledge given by the epistemic framework. Religious traditions typically distinguish between religious and secular knowledge traditions, conceiving the latter as being ancillary to the former. Thus Jewish and later Islamic traditions distinguish between transmitted and rational sciences.[47] In the case of Islam, the first, the Koranic sciences, comprised Arabic grammar, lexicographic writing, Koranic exegesis, Islamic law, the edifying life of the Prophet, and heresiography, among others. Secular knowledge comprises geography, history, poetics, astronomy and mathematics, the latter considered useful for solving inheritance problems. Philosophy, in contrast, was evidently never accepted as an essential part of higher Islamic learning. One of the reasons is that, in Islam, orthopraxy, a set of behavioral norms, plays a more important role than orthodoxy, a set of beliefs that can not only be interpreted, but also extended with the help of philosophy. Another reason is the fragile institutional support for the pursuit of higher secular learning in traditional Islamic societies. The worldly sciences were cultivated at the courts and suffered the precarious situation of patronage.

Buddhism, too, as a text-based religion, furthered the accumulation of knowledge related to the exegesis of texts, in particular, grammar, logic and rhetoric. Given the epistemic focus of Buddhism on liberation from the self and its constraints, secular knowledge related to the mastery of the physical world was not cultivated within its tradition.[48] Also the extent to which knowledge production becomes institionalized depends on the dominant epistemic constellation: While philosophical knowledge, including the philosophical implications of modern science, was relevant to Greek-speaking Orthodox Christians in the Ottoman Empire, experimental knowledge and practices were not.[49] The reason was that such knowledge played a role in constituting their intellectual and cultural identity, but

[45] See chapter 12.
[46] See chapter 14.
[47] See chapters 12 and 13.
[48] See chapter 10.
[49] See chapter 14.

not in the construction of a social system of scientific research and education that remained beyond their reach. In general, the emergence of theoretical knowledge from the reflection of practical knowledge about the material world was a rather exceptional historical event. And even when it happened, as was the case in European and Chinese antiquity, it risked remaining an inconsequential singularity as long as such a coupling of theoretical and practical knowledge did not become part of a system of knowledge with a strong societal underpinning. In China soon after its emergence, the scientific tradition was, in fact, interrupted, while traditions of practical and technical knowledge continued that were part of *Herrschaftswissen* (knowledge relevant for the exertion of control and power) such as calendar making and astronomy.[50]

While religious traditions assemble heterogeneous packages of knowledge, they nevertheless tend to achieve coherence, consistency and completeness on the level of the meta-knowledge at their core. Thus, in Buddhism, as in Judaism, Christianity and Islam, sects competed in attempts to create a consistent system of thinking. They all strove for a closed, sometimes even totalitarian, worldview, immunized against the challenges provided by the inevitable assimilation of new knowledge.

9.7 The Impact of Different Forms of Knowledge Representation

To better understand the conditions for the transmission of higher-order knowledge, we turn once more to the issue of external representations of knowledge. Higher-order knowledge comprised by religious traditions and *Herrschaftswissen* relevant to imperial rule, from accounting techniques via astronomical knowledge to the distinctive literary or religious knowledge of elites, were systematically transmitted by often fragile social institutions that relied on oral traditions, texts and visual representations. No empire in history was able to advance without an economy of knowledge whose functioning determined to a great extent the potential of its leaders to exert control over society. A specific historical economy of knowledge also depends on the state of information processing: Roman archivists, for instance, ordered their holdings according to year and not to subject and were thus hard pressed when it came to finding a particular file. And even such primitive infrastructures tended to last only as long as the political structures in power (Heather 2006). Over the longest period of history, higher-order knowledge reflecting on practical knowledge and resulting in the cultivation of sciences such as mechanics, optics, medicine, or mathematics, was transmitted only occasionally and merely as a by-product of the transmission of these other forms of higher-order knowledge. No automatism existed for the spreading of higher-order secular knowledge. The existing global networks, for instance of commerce or religion, did not even necessarily spread the knowledge that made them possible in the first place,

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[50]See chapter 11.

for instance, about communication technologies or mobility. Maps, for instance, were closely guarded by the Portuguese crown as part of their *Herrschaftswissen.*

The relative importance of the different forms of knowledge representation, oral, literary, visual, and the extent of institutionalization varied greatly for different traditions in a way that was largely determined by the dominant epistemic constellation. The Vedic tradition, for instance, was transmitted orally in accordance with the view that Sanskrit is a sacred language within a rigidly stratified society in which access to knowledge is a class privilege. Buddhism, in contrast, was coded in writing, in accordance with the view that language is merely a conventional means of communication.[51] Nevertheless, the translation of Buddhist texts into a great variety of languages constituted a major challenge, requiring the creation of new terminologies to represent this knowledge. Addressing this challenge of representation triggered the generation of new knowledge, in particular linguistic and philological knowledge. The ways in which this challenge was taken up differed widely in dependence on the diverse forms of transmission processes by which Buddhism traveled and in keeping with the dominant epistemic constellation of the appropriating society.

The essential message of Buddhism was represented not only by the canonical scriptures but also by visual representations of the Buddha and by the monastic community, the latter constituting a social form for the transmission of knowledge later adopted also by Christianity. Since the transmission of Buddhism depends strongly on institutions, this could be interrupted if these institutions were destroyed, as happened in eleventh- and twelfth-century India due to the Muslim invasions. Nevertheless, both in Buddhism and Christianity monasteries provided shelters for the transmission of texts and knowledge in situations of economic decline, political upheaval or military destruction. As is well known, key texts of classical antiquity survived in the monasteries of Christian Western Europe where they were copied or used as palimpsests.

In Islam, the social transmission of knowledge did not rely on monasteries, but initially merely on pious circles gathering in private homes or in mosques. Only under the Seljuq Dynasty in the eleventh century did a system of state madrasas emerge which spread widely through the Islamic world.[52] The extent to which secular knowledge was covered by their curricula varied greatly, but mostly they served as centers for spiritual training with an emphasis on calligraphy, Arabic language and grammar, Islamic theology and ethics. In traditional Islam, the flow of knowledge was also regulated by other institutions, with a particular emphasis on normative issues. Knowledge about correct social behavior, for instance, is controlled by experts on Sharia. Their argumentation typically relies on paradigmatic examples taken from the first three generations of Muslims. In addition, there is the system of Fatwas by which Islamic scholars express religious opinions, responding to new challenges and offering pious advice.

[51] See chapter 10.
[52] See chapters 12 and 13.

Access to knowledge is not solely regulated by institutions but is also mediated by the very material employed for its external representation. The long-term sustainability of the political system of traditional China relied not only on stable institutions in which the transmission of knowledge was coupled with access to power through the examination system of scholar-officials. It also relied on the existence of a book culture in which such knowledge could be stored, distributed and made accessible throughout the empire. This book culture in turn depended on the availability of cheap paper and the invention of printing, making it possible to recollect and transform the knowledge accumulated over centuries within each new dynasty. Similarly, the rapid assimilation of ancient knowledge as well as its dissemination and elaboration in early Islam was favored by the existence of paper as a cheap writing material. Scholarly communication and collaboration across a vast territory was indeed significantly aided by the trade and exchange of affordable books. To some extent, the early Islamic book culture even compensated for the fragility of institutions by ensuring the survival of the accumulated knowledge when the support for scholarly activities by patronage broke down. Paper and the techniques of paper making were transmitted to Christian Europe from Islamic Spain from the early twelfth century. Paper thus arrived at about the time of the emergence of universities as sites of higher learning in Europe, substantially extending the role of monasteries in the earlier Middle Ages. The rise of scholasticism as a Europe-wide network of higher learning and scholarly exchange would have been unthinkable, not only without the influx of classic texts from the Islamic world, but also without the emergence of new forms of representing and transmitting knowledge.[53]

As a rule, changes in the medium of external representation affect even the architecture of knowledge itself as well as, evidently, the conditions for its transmission. Without newly available books as containers of European technical knowledge, the Jesuit transmission of European science and technology to China would not have been possible, nor would the revival of some of this knowledge in China 250 years later. Another condition for this transmission was, of course, the existence of a shared domain of knowledge embodied in technologies that were available both in China and Europe such as mechanical devices. To give another example, when the Arab printing press was introduced in the eighteenth century by Christian church authorities in Syria and Lebanon, and when newspapers and magazines became available in the Arab-speaking world, the conditions for access to Western scientific and technological knowledge improved considerably, as did the availability of orientation knowledge about the global political situation.[54] But not only the access to secular knowledge became democratized, but also access to Islamic cultural heritage. The classical works of Islam were now also accessible to a broader public, with far-reaching implications for the implementation of Islamic normativity. Traditional inner-Islamic conflicts emerged on a global scale because

[53]For a discussion of the role of printing, see (Febvre and Martin 1990; Giesecke 1991).
[54]See chapter 12.

people in one region realized that people in another followed different beliefs and practices. At the same time, the mass media also reinforced the consciousness of belonging to the *umma*, the global community of Islamic believers that is now a historical actor in the globalized world.

From the beginning, the new media thus opened up multiple paths to modernity because they catalyzed the spread, not just of Western ideas of development, but also their alternatives.[55] With the arrival of the Internet, Muslims became able to access normative Islamic knowledge from anywhere in the world, and also to remix and combine Islamic norms in new ways with secular knowledge. Such developments actually considerably predate the advent of the Internet. Exploiting the potential of industrialized print media and the creation of networks of communication across wide areas, Islam already had begun to become a mass ideology in the early twentieth century. Similarly, the development of modern science in colonized territories such as India relied on heterogeneous networks of research and teaching in which aspects of Western modernization were mingled with local traditions.[56] Since the mid-nineteenth century, outside of Western Europe and the United States, collaborative international networks sustained by modern means of communication have doubtless become, for science, religion and ideology, the major conduit for knowledge production and exchange, much more important than any local institution.[57] One should not forget, however, that within such networks, scientific knowledge traveled, not just in the form of ideas and writings, but also in the form of material objects such as measurement instruments or other objects embodying high technology. In fact, their travel constituted an important channel for the globalization of material and cultural practices crucial to the spread of science.

9.8 Knowledge Transmission Processes Between Self-Reinforcement and Immune Reaction

Transmission processes in which knowledge spreads as a fellow traveler are often characterized by increasing the significance of knowledge as they proceed and may actually turn into intentional and directed processes of knowledge transmission. One of the reasons is the systemic quality of at least part of the transmitted knowledge, with the consequence that one piece of knowledge points to others and hence tends to reconstitute the system. Another reason is the empowerment which the gain of knowledge typically signifies for the receiver. But systems of knowledge may also become atomized when spreading as a fellow traveler so that isolated chunks are transmitted in a highly mediated, indirect and unintentional

[55] See also (Eisenstadt 2000, 2002).
[56] See chapter 15.
[57] Modern means of mass communication have also contributed significantly to shaping national identities in non-Western areas, as in the case of Indonesia where the spread of nationalistic ideas by mass media preceded state formation; see (Anderson 1996).

way, while being continuously recontextualized. The conditions which initially favor the transmission process impose constraints on it that may eventually hinder the transmission of knowledge, in particular when other transmission processes do not follow suit and when the production of new knowledge remains unilateral. Successful transmission processes presuppose that originator and receiver share aspects of material culture and basic knowledge that are not transmitted. Even more importantly, their sustainability presupposes a reciprocity between originator and receiver, turning them into equally significant nodes of a network of knowledge transmission. When the dominant epistemic constellations differ between receiver and transmitter, the transmission of knowledge unavoidably amounts to a transformation of knowledge.[58] A transformation of this kind occurs because the motives and structures of the appropriation of knowledge by the receivers differ from those of the transmitters. As a consequence, the transmitted knowledge is reconstituted in novel ways at the receiving end, governed by the dominant epistemic constellation, and often with repercussions for the originator. But under certain circumstances, the transmission of knowledge may also induce a change of the dominant epistemic constellation, typically when the existing constellation is in a crisis for other reasons. A change in the dominant constellation primarily induced by the influx of new knowledge is a characteristic of socioepistemic evolution and usually does not happen as long as knowledge is just a fellow traveler. Examples for the dynamics discussed in this section range from religious missionary activities to colonial science.

Buddhism, for instance, on the whole spread rather randomly, even after it had become a state religion in the third century BCE under Aśoka, the ruler of Magadha, who also fostered missionary activities.[59] Some of its conceptual assets, such as the story of the life of Buddha or the notion of hell, also spread by way of a highly mediated and indirect transmission to Christianity, obliterating their origin from a complete system of thinking. Yet, when Buddhism first took hold in a new context, for instance in China, it typically triggered activities on the part of the receiver toward the acquisition of new texts and new knowledge.

A similar process of self-accelerating transmission took place in the twelfth-century Arabic-Latin translation movement.[60] The translators were a group of self-appointed men, mostly from the lower clergy, who traveled from all over Europe to the emerging translation centers in an effort to gather new knowledge from their translation activities. They were fascinated by an alien and hostile culture supposedly in possession of superior knowledge that was believed to potentially constitute a powerful asset for Latin culture as well. Eventually, however, their efforts set in motion a self-accelerating process of knowledge acquisition. In the first step, it was mainly practical interests that motivated the translations; in the

[58] For elaborate studies of such transformation processes, see the works published in the context of the Collaborative Research Center 644 "Transformations of Antiquity," in particular (Renn and Damerow 2007; Damerow and Renn 2010; Böhme et al. 2011).

[59] See chapter 10.

[60] See (Abattouy et al. 2001b), on which the following is largely based.

second step, missing pieces of knowledge were systematically sought; in the third step, institutional and epistemological adjustments took place in dealing with the newly acquired knowledge; in the fourth step, the transmitted knowledge was reproduced and extended in a new context. Important monasteries in the twelfth century were engaged in reforms that included revisiting ancient knowledge in the context of their educational mission. While initially the hunt for new texts somewhat resembled the search for the Holy Grail, represented for instance by the secrets of astrology, the later phase was characterized mainly by organized efforts to fill the gaps in a system of science that had become gradually familiar.[61] As an alternative to a gradual emergence of a culture centering on the newly acquired knowledge, consider the complete transformation of Tibetan culture in the seventh century by the decision of the king to adopt Buddhism, and the ensuing adoption of an appropriate writing system and comprehensively organized translation activities.

Translation processes are an important medium for the transmission of knowledge, in particular when knowledge is represented in writing, and are always faced with a double challenge: a mapping between two languages, and a mapping between conceptual systems that are not usually coextensive or even compatible with each other.[62] Addressing the second challenge not only requires mastery of the contents, but often also new linguistic resources created in the course of the process. These may range from the creation of a lexicon of technical terms to that of elaborate grammars and other forms of reflection on language. As the history of Buddhism illustrates, the transmission of knowledge may hence become itself the source of new knowledge about language. The way such knowledge is created very much depends on the relevant epistemic constellations, in particular, that of the target area. While in the Tibetan case of translating Buddhist scriptures, systematic aids were created that embodied linguistic meta-knowledge, such knowledge remained implicit in the case of translations into Chinese, being represented instead by paradigmatic examples.

The very possibility of translation depends on the existence of cultural overlap, that is, of a shared basic material culture, of shared knowledge, of compatible motives and of the existence or the possibility to create or exploit multilingual environments. Indeed, most translators of Buddhist texts into Chinese came from the multilingual environments of the cities along the Silk Road and of the Persian Empire. Similarly, the Greek-Arabic translation movement involved Christians, Sabaeans, Jews, Persians and Muslims. The Arabic translators of Greek philosophical or scientific texts were not simply dealing with a dead culture, but with a living tradition still involving active scholars.

[61] See (Lemay 1962, 1963, 1977; Burnett 2001) and the discussion in (Glick 2005, 313 ff.).

[62] For a comprehensive study of the relation between translation and globalization, see (Cronin 2003), who emphasizes the importance of translation in processes establishing hegemony and its antagonisms. The transformative and generative power of translation in the context of globalization processes has been stressed by (Ning 2008, 75–87).

Successful translation movements typically involve several phases of translation activities, where, in the first phase, the emphasis is on linguistic challenges. In the second phase, it may shift to challenges of content due to the gradual build-up of an autonomous intellectual culture able to deal with the newly acquired knowledge, as was the case for the Greek-Arabic translation movement. Often translations proceed with an alternation between oral explanation and written documentation. This was the case for the translation of Buddhist texts into Chinese, and later for that of European scientific texts into Chinese. Translation processes involve, in any case, a combination of competencies that often require intercultural cooperation. They also involve a negotiation about different and often mutually exclusive goals. These goals range from a faithful rendering of the original linguistic structure to the reconstruction of the original content with new means in a new medium. As a consequence, either basic knowledge about the content is transformed and partly lost in translation, or its original linguistic representation is distorted, interfering with the possibility of rendering certain higher-order connotations of the original meaning. These connotations are in fact often represented by semantic links within the wider field of language and hence reside in the context rather than in the text. (A perfect translation is only really possible when it is no longer necessary.)

When, for instance, a new terminology is created to faithfully render the "technical" contents of an original source in the target language, then this terminology has little chance of resonating in the same way with a semantic context in the new language as the original terminology could within the source language. Conversely, the creation of such a new terminology may create new semantic fields, hence effectively changing the target language in a way that is shaped by the transmitted contents. This was the case for many Asian languages as a result of the transmission of Buddhism. Similarly, while the early modern translations of European scientific texts into Chinese had little immediate impact on the Chinese knowledge system, they did help to prepare the linguistic ground for the appropriation of European science more than two hundred years later.[63]

This case also illustrates another limit of the translation process: the communicability of higher-order knowledge specific to the source culture. The Chinese rendering of early modern European scientific texts typically resulted in compilations and hybridizations of several texts rather than translations of a single one.[64] In these Chinese versions of European scientific knowledge, the deductive structure prominent in some of the original sources is de-emphasized or even omitted. There was in fact no corresponding structure for organizing knowledge in the Chinese tradition that offered itself for a mapping of European-style deductivism. A mere linguistic rendering of this structure within the Chinese language, which was of course possible, could do little to implement this structure within the Chinese system of knowledge. Translations of single texts, even when performed as part

[63]See (Amelung 2001).

[64]See chapter 11.

of a translation movement, are operations within the realm of individual knowledge and have limited impact on the fate of the shared knowledge of a culture. Paradoxically, precisely the adequate transfer of higher-order knowledge by way of translating texts can succeed only if more primary knowledge is transferred as well, along with the social structures for its generation and transmission, so that the dominant epistemic constellation may change and no longer hinder a more comprehensive transfer of knowledge.

The dominant epistemic constellation, however, is hardly ever directly destroyed by knowledge spreading as a fellow traveler but rather determines, conversely, how incoming knowledge is selected, rejected, or appropriated. This is not to say, however, that it may not be undermined by knowledge "smuggled" in. When the Jesuits brought European scientific knowledge to Ming China, mainly the parts that resonated with the Chinese *Herrschaftswissen* were filtered out; these included military technology, calendar making, geography, and so on. Similarly, Greek-speaking scholars appropriated new scientific knowledge, for instance about Newtonian science, neither with the effect nor even the intention of changing the dominant epistemic constellation from which they benefitted as an intellectual and political elite of the Ottoman Empire.[65] They rather selected those parts of modern knowledge that were most suited to the reinforcement of their traditional Aristotelian philosophical views. As a result, the system of knowledge constituted by early modern European science was neither transferred completely nor in part, but was instead entirely disassembled under the spell of a different epistemic constellation. Yet in both cases, the transfer of new knowledge did eventually help to create the conditions for a change in that epistemic constellation when this actually took place for other, political, economic and military reasons.

In the nineteenth and twentieth centuries, European imperialism, colonialism and later decolonization were among the most significant driving forces for major changes in epistemic constellations in connection with the introduction of Western science in non-European regions. Indeed, the expansion of modern science was linked with European colonial expansion, just as the spread of religion was often linked with the building and expansion of empires. In India, North Africa and the Middle East, for example, the transmission of European knowledge only worked on a major scale—at least if compared to that of previous centuries—because it was now part of a system change. Now the new knowledge arrived with new structures of power, new educational institutions, with career opportunities despite conditions of inequality, with a growing autonomy of local knowledge production, and with the promise that the new influx of knowledge would eventually help to overcome the conditions of submission, expropriation and repression created by the imperialist powers. In many Islamic societies in the nineteenth century, for example, European educational institutions gradually gained more importance than the traditional ones, providing students with access to Western science. A similar development took place in India and other colonized territories, fostered by

[65]See chapter 14.

a variety of motives, from missionary goals to the need for the colonizing powers to educate a technocratic elite and ensure the governmentality of the occupied lands. Modern educational institutions were introduced to train technical personnel for public works and engineering useful for the colonial state.[66]

The transmission of new technological and scientific knowledge under the conditions of external pressure often provoked an immune response, mobilizing or newly inventing local knowledge traditions.[67] Their purpose was to create a second-order epistemic framework in which the appropriation of the new knowledge could be interpreted as a reinforcement rather than an alienation of the local cultural identity. In India, for instance, such a mobilization led to attempts to revive and reinterpret traditional Ayurvedic medicine in terms of Western medical and pharmaceutical knowledge. In China, the challenge of new knowledge was addressed by reinterpreting it as a return and revival of lost ancient Chinese knowledge. Similarly, in certain Koran interpretations, telephones, planes or electricity are conceived as having already been predicted in the holy text. Also due to such immune responses, the transmission of Western technological and scientific knowledge did not automatically function as the conduit for a Western-type modernization, including a secularization in which such knowledge is expected to undermine religious or other traditional belief systems. Ultimately, however, the promise of modernization due to technological, economic and social development associated with the transmission of Western science usually overrode attempts to interlace it with local knowledge traditions, unless the latter turned out to be useful in compensating some of the pitfalls of colonization and modernization. One example is the appropriation of local agricultural products by Western settlers and colonizers with the help of indigenous populations.

Eventually, and in particular in the process of decolonization and the emergence of the new, post-colonial nations, it was the educational and academic institutions rather than the knowledge structures and contents themselves that were localized in the sense of being tuned to the goals of political and economic autonomy associated with scientific and technological self-reliance.[68] Thus, as the example of post-colonial India illustrates, new epistemic constellations emerged that were modeled on the Western paradigm, but situated in an environment with substantially different preconditions for their penetration to society at large, beyond the social stratum of post-colonial technocratic elites. As a consequence, epistemic islands are formed, for example, large scientific centers where mission-oriented research is pursued. These epistemic islands are linked to their home society predominantly by top-down mechanisms of political, economic and military control. At the same time, these islands are part of the network of globalized science, with external links of communication and cooperation prevailing over in-

[66]For case studies dealing with the African situation, see (Omenka 1989; Ndongmo 2007). Valentin Y. Mudimbe calls the colonial education system “violence” (Mudimbe 1997, 61).
[67]See chapter 15.
[68]See chapters 15 and 18.

ternal ones. Within this global network, the epistemic islands of the larger South play a peripheral, but creative, role in international knowledge production; this is due as well to their remoteness from the intellectual control mechanisms, such as peer pressure dominating at the more central nodes.[69]

From the beginning of the twentieth century, with the failure to generalize and spread the dynamics of modernization beyond privileged islands, shared epistemic frameworks associated with religious and other traditional belief systems stood a chance of reactivation. Shared epistemic frameworks, such as those of traditional Islam in North Africa and the Middle East had been marginalized, but were still lingering in the background.[70] Now the immune reaction could become a rejection reaction, not so much specifically of the knowledge transferred from "outside," but rather of the dynamic and threatening role of knowledge more generally, even that rooted in the traditional belief systems themselves. While religious fundamentalists may be open to the use of advanced technologies and other assets of the modern world, they are indeed radical in their rejection of any possible impact of any kind of knowledge on the fundamental principles of their belief system. Paradoxically, they have driven the Western logic of enlightenment, which they reject, to its extreme. The split between factual and normative knowledge, traditionally considered to be an achievement of Western Enlightenment, thus has turned into the ultimate immunization scheme for protecting the epistemic core of fundamentalist belief systems against the unsettling effects of the transmission and appropriation of new knowledge.

9.9 Science as an Insular Phenomenon

In summary, for most of human history knowledge has been a fellow traveler in the sense of being subject to political, economic or religious interests rather than being itself the main driving force of societal developments. Knowledge spread with the rise and expansion of empires, along trade routes, and with the diffusion of religious belief systems. Its transmission was thus largely subject to extrinsic dynamics, which also determined its constitution in terms of systems or packages of knowledge. Nevertheless, the spread of knowledge as a fellow traveler also unfolded significant intrinsic dynamics that affected later phases of the globalization of knowledge. The transmission of knowledge may exhibit a self-reinforcing quality, strengthening the significance of knowledge as it proceeds. The spread of knowledge stimulated, for instance, the creation of new media and new institutions for its transmission. Also the production and spread of knowledge enhanced the conditions for other, extrinsic expansion processes such as conquest and colonization, which in turn fostered the globalization of knowledge, but at the same time, also its destruction.

[69] Developing countries have adopted different strategies for science policy with varying degrees of success. For a review, see (Gibbons et al. 1994, 132–33).

[70] For more on this, see (Eisenstadt 2000).

Religious belief systems, and in particular the world religions, often represent another fellow traveler of political, economic and military expansion. And yet, their spread is also subject to significant intrinsic dynamics due to their potential autonomy from societal rule, their self-referential traditions of religious learning and their universalist claims. For this reason, they have become increasingly effective carriers of knowledge as a fellow traveler than empires or commerce. But religions (or quasi-religious belief systems, such as nationalism) have had an even deeper impact on the globalization of knowledge. As collective representations of shared basic human experiences, in an essential way they shape the dominant epistemic constellation determining the place of knowledge in a society under their spell and hence also the boundary conditions for any transmission of knowledge. In comparison with the success of religions as forms of shared meta-knowledge, the rise of higher-order knowledge resulting from a reflection on material interventions leading to science was historically rather exceptional. The survival of such scientific knowledge depended strongly, moreover, on resonance effects with the dominant epistemic constellation, as it took place in early modern Europe (see section 9.4). Only when these resonance effects lasted sufficiently long could such higher-order knowledge about the material world in turn affect the dominant epistemic constellation—with powerful implications. Against this background, it becomes understandable why scientific knowledge emerged several times in history, but only once achieved a lasting global impact on human development.

The systems of modern scientific knowledge spread as fellow travelers of political, economic, military and religious processes too. They also spread, of course, by way of self-accelerating intrinsic dynamics constituting globalized science with its worldwide network of institutions, its advanced communication technologies and its fundamental role for world economy. But even when science becomes globalized, it may still constitute a merely insular phenomenon within a given society and hence remain a fellow traveler of other societal processes, with the consequence that its reflective dimension and transformative power are largely cut off. Accordingly, both spreads may affect societies only on the surface because they do not necessarily involve a change in the dominant epistemic constellation. Indeed, the spread of modern scientific knowledge takes place within a historically shaped landscape still characterized by diverse epistemic constellations. These constellations as a rule do not exhibit the same resonance effects that were at the origins of the emergence of Western science and its transformative power. While locally dominant epistemic constellations may no longer regulate the global network of science, they do determine the place of knowledge in the local society at large. However, since the impact of modern science on a given society is no longer necessarily mediated by its dominant epistemic constellation but by encompassing globalization processes, the retroaction of scientific knowledge on the local epistemic constellation is also no longer immediate. In other words, the dynamics of the globalization of science and of knowledge in a more encompassing sense are effectively decoupled from each other—at least as long as knowledge remains a fellow traveler.

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Chapter 10
The Spread of Buddhism as Globalization of Knowledge
Jens Braarvig

10.1 Basic Tenet of Buddhism

Buddhism, as one of the three "World Religions,"[1] a universal creed with a global following, represents to a great extent an autonomous field of knowledge, in the same way as Christianity and Islam, even though these three religious traditions are intertwined with other conceptual systems in origin and throughout their histories. Thus, the first question must be what is or constitutes such a conceptual system, and the second, which fields of knowledge does this conceptual system create in the process of historical and geographical diffusion. In addition, the second question must also address the processes of diffusion and how the modes of knowledge are communicated.

The basic tenet of Buddhism is the idea of impermanence, relativity and the philosophical premise that nothing is absolute and eternal: existence is an everlasting flux, and each entity is dependent on another. This tenet gives the tradition its identity as distinguished from other ancient traditions of India in whose context Buddhism originated. Thus, believing in an eternal self, the basis of all Brahmanical philosophy, to which the Buddhists aimed their philosophical and rhetorical skills, was according to Buddhist insights the most basic misunderstanding of all: believing in and trying to find a *self*—or *oneself*—will always keep sentient beings attached to existence. Giving up the hope that anything is permanent, however, will eventually liberate men from bondage and the circle of rebirth to which we are all doomed by the fruits of our actions "since beginningless time," as it is expressed in Buddhist literature. There can also be no eternal god, nor any basic cause of existence: everything is created by the actions of sentient beings in various states of existence, men, gods, animals or various classes of spirits. We see that Buddhism in this way is based upon what we might term a philosophical or even a

[1] Judaism and Hinduism are now also traditionally seen as "World Religions," but since one is born into them, and access is limited by ethnicity, they might be counted as ethnic religions in that sense. Christianity, Islam and Buddhism, on the other side, in principle are not limited by ethnicity or birth, being universal and missionary movements, though in most historical situations, the various sects and schools indeed have been closely linked with national and ethnic identities. In respect of the globalization of ideas, Judaism is very much a universal religion, being the historical basis of both Christianity and Islam; and Hinduism, historically spreading Indian culture throughout South-East Asia, and with diaspora and missionary activities in modern times, may also thus be styled a "World Religion."

psychological tenet, rather than faith in a transcendent being or a metaphysical reality, a philosophical premise that remains as such in the various philosophical transformations of Buddhism throughout its history. The basic premise of Buddhism, then, can be seen as less a creed based upon faith than an attempt to formulate a philosophical or "rational" premise for the system of knowledge, even though much of Buddhism of course seems irrational in the modern sense. However, this semi-rationality of Buddhism makes it easier to study as a conceptual system producing fields of knowledge, and it can be studied as a fairly limited or closed conceptual system.

10.2 Geographical Spread of Buddhism

In short, the spread of Buddhism is as follows:[2] It originated in the mid-north of India in the fourth century BCE and spread to Sri Lanka in the late third century BCE by missionary activities. The first visit of Buddhist monks to the Imperial Court in China is dated in the seventh decade CE, during the Han dynasty, but it is only from the late second century that the activities of translating Buddhist scriptures into Chinese gained momentum. From the centers of power in China, like Xi'an or Chang'an, Buddhism spread to Korea, to Vietnam, and to Japan just after 600 CE, as introduced, according to tradition, by Prince Shōtoku, and then later to Mongolia—in this case from Tibet. The spread of Buddhism to the Far East took place both randomly by way of the cultural, commercial and popular communication along the Silk Road through Xinjiang north of Tibet, but also as a result of learned missionary activities along the same route including a long tradition (second to eleventh century) of translating Buddhist texts from Sanskrit and Pāli into the Chinese idiom gradually created for that purpose. There was also a sea route from India to China, which is well documented. Chinese scholars took this route to India to study and bring home the sacred texts and teachings. In the seventh century, the Tibetan king Songtsen Gampo (CE 617–650) decided that his kingdom should adopt Buddhism, influenced, according to legend, by his Nepalese and Chinese brides. According to tradition, he had Tibetan writing established on Indian models to serve as the vehicle for introducing Bud-

[2] For the origin and early spread of Buddhism in India and the neighboring regions like Sri Lanka and Gandhāra, see (Lamotte 1988). On the North-Western diffusion and the origins of the writing systems, see (Salomon et al. 1999), and on the crafts that accompanied the spread of Buddhism into Central Asia, see (Cribb and Errington 1992). For the South- and Southeast-Asian diffusion, see (Bechert 1973). Another classic is (Coedès 1968), further in (Skilling 2009) and (Pande 2006). The monumental *Buddhist Conquest of China* by Eric Zürcher (1959) is still most useful; for Korea, see (Buswell 1989); and for Japan, (Bowring 2005); and in general (Heirman and Bumbacher 2007). For the Tibetan case, see (Kapstein 2000), with its ample bibliography. A comprehensive and up-to-date bibliography of Buddhism is (Sueki 2008); see also (Bingenheimer 2011). The details and dates of the introduction of Buddhism to the mentioned geographical areas sometimes build on very meager evidence, sometimes tending to the mythical rather than the strictly historical, and are thus contested by scholars. For a overview of Buddhism, see (Freiberger and Kleine 2011).

dhism to Tibet. The Tibetans at the time were a warlike people and under King Thri Songdetsen (CE 755–797) they beleaguered the Tang capital of Chang'an in 763; although they had an efficient military organization it was the king who finally fully adopted and supported Buddhism. From Buddhism as adopted by the Tibetans, the creed and the system of knowledge spread further into Central Asia. What the original Sanskrit language was to Tibetans the Tibetan language became to the Mongols: the sacred language from which they translated their Buddhist classics. Due to the increasingly frequent Muslim invasions into India from the eleventh century on, Buddhism, as a religion very much dependent on strong institutions—those of monasteries and the great Buddhist centers of learning—was uprooted from India during the eleventh and twelfth centuries, and India was no longer the main source of Buddhist learning. Thus, the traditions lived on in East and Central Asia on the basis of the translated canonical scriptures, and the knowledge of the original Buddhist languages was soon lost in these areas. The southern traditions of Buddhism, however, those of Sri Lanka, Thailand and Burma, have kept their canons in the original Pāli language, which they have continued to study throughout the centuries, unlike the "Northern Traditions" which forgot the original languages of Buddhism and expressed Buddha's words in their own languages. An exception to this, though, is the Buddhism of Nepal, which has kept a tradition of Buddhist Sanskrit literature up until the present, even though Nepalese Buddhism with time became interwoven with Hindu traditions.

The diffusion of Buddhism during the second millennium CE was not nearly as intense as during the first when the Buddhist traditions thrived in the various "national" formats in East, South and Central Asia, as based upon translations of the canonical scriptures. However, one can argue that Buddhism became fully globalized only in the twentieth century, when to some extent it reached the Western countries. Four modes of diffusion can be mentioned in this respect, namely: romantic interest in the exotic from which ensued a fragmented and inaccurate knowledge of Buddhism (and other exotica), mostly from the eighteenth century on; systematic academic study which gained momentum from the middle of the nineteeth century; Buddhist missionary activities; and the spread of Buddhism by migration. The last two stemmed mostly from the mid-twentieth century, but were not completely absent before that. These four modes are intertwined and dependent on each other to some extent, and Buddhism is growing rapidly in some countries.

From its humble origins in the fourth century BCE with its founder Gautama Śākyamuni, Buddhism was established organizationally and politically in the third century BCE under the sponsorship of the Indian emperor Aśoka, who ruled from 273–232 BCE. Mahinda, Aśoka's son, brought the Buddhist creed to Sri Lanka, where according to tradition the Buddhist canon was written down for the first time in the late second century BCE. In this part of the Indian subcontinent, the Buddhist tradition remains unbroken up to the present day. The Buddhist tradition, as exported to the island of Sri Lanka, was also the basis of the traditions that developed and remained until the present day in Thailand and Burma.

10.3 The Importance of Literacy in Buddhism as Opposed to Orality in the Hindu Traditions

Writing is of great importance for the transfer of knowledge and played a crucial role in the diffusion of Buddhism. However, writing was introduced astonishingly late to the Indian subcontinent and the development of writing seems to have been closely connected with the promulgation of Buddhism. Indian tradition is first of all oral; the Vedic lore has been transmitted from teacher to pupil over centuries and millennia, and with astonishing accuracy. The Vedic tradition also held that the Sanskrit language was sacred to the extent that it was the language of the gods and of the ultimate reality itself. Thus, preservation of the knowledge of the sacred tradition was the prerogative of the higher castes; it was a secret body of knowledge not to be divulged to the lower castes or to those outside the caste system. To Buddhists, however, language was simply a conventional means of communication, and the canonical stand of Buddhism is that the *meanings* of words are more important than their form. Thus, language is not essential, but should be able to convey Buddhist truths in an appropriate way. Buddhists would fully exploit the written word as the main vehicle of their propagation of Buddhism as never before in India.

In many respects, Buddhism was in its origins and throughout its history in India in continuous opposition to Hinduism. It originated as polemics against *Brahmanical* traditions, which maintained that the universal self, being ultimately the same as the individual self, was the basis of existence as a whole, while the Buddhist, in view of his doctrine of *anātman*, "no-self," would assert that believing in such an entity would be the greatest misunderstanding of all. This came to have a profound influence on the respective views on language, and also writing. Buddhists would assert that language is only a conventional agreement on which sounds of language referred to a particular object, while the Brahmanical-Hindu traditions would through its continuing philosophical and doctrinal discussion and disagreement with Buddhism assert that each word of the Sanskrit language corresponds to an ultimately divine entity. In this relativist-essentialist discussion, to use a modern expression, it is clear that the Buddhists saw language as a practical means of communication to convey a meaning conventionally expressed by language, and also similarly viewed writing. The Brahmanical tradition on the other hand retained the eternal sacredness and secrecy of its language without committing it to writing, since the divine language is basically *sound*, the spoken word. Thus, the mnemotechnics of archaic and classical India is surprising; even works such as the complete grammar of the Sanskrit language by Pāṇini (fifth or fourth century BCE) with all its meticulous detail and intellectual brilliance, was transmitted orally over the centuries, as was the basic "etymological" dictionary, the *Nirukta*, in addition, of course, to all the other religious, philosophical, epic, and poetical "literatures."

In view of this philosophical and doctrinal background, there was no hindrance to the promulgation of the Buddhist doctrine *both* orally and literally. The medium of writing was perfectly suited to the communication of the Buddhist creed as it did not nurture any notion of a divine *lingua sacra*. The teachings of Buddhism are seen by many modern readers as being styled by a psychology of liberation rather than a religious creed, with a pragmatic and rational aim rather than a religious one: it is repeated again and again that the practitioner of Buddhism must "find out for himself" rather than believe in one particular system or faith. That Buddhism is thus a "rational psychology" has been exploited by modern Western adherents of Buddhism, and as such considerably exaggerated. But in the discussion with the Hindu tradition, Buddhism indeed had a more pragmatic relation to language, not regarding it in principle as sacred. However, in practice, wherever it spread Buddhist literature also became mantras and *voces magicae*, and the literature was read rather for the sound of the reading and magical effect than for understanding its content. This was a fairly limited form of transfer of knowledge, but of course a frequent phenomenon in religious history. But still, while the Vedic lore could be apprehended only in spoken Sanskrit, any language was suitable for Buddhist teaching, as long as it could convey its meaning. Thus, what are considered to be the oldest Buddhist scriptures are not written in Sanskrit, but in the Sanskrit dialect and descendant of Sanskrit, Pāli, which became the most important literary Buddhist language for the southern branches of Buddhism. Of the other important dialects of Sanskrit used by the Buddhists one finds the Gandhāra language, as employed by the North Western branches of Buddhism, and what has been styled "Buddhist Hybrid Sanskrit" by modern scholarship, where the relation of the written language to spoken dialects is unclear. It is even possible that some of these languages were purely literary languages.

As the Greek historiographers testify, when they came to the East after Alexander's conquests just before 300 BCE, the Greeks were very surprised that the Indians, who had no writing systems, were able to rule their kingdoms without written laws. However, it did not take long before writing was introduced, with inspiration from the West, in India. The Persians indeed employed writing in the administration of their great empire, of which north-western India was a part, but there is no evidence that the Indians made any use of writing (excepting the Indus script) before the great emperor Aśoka employed writing for a particular purpose, namely to promulgate his ethics and religious sentiments throughout his empire. Aśoka's edicts, mostly carved in stone but also on other material such as iron, are still preserved and bear witness to a ruler who protected religious and ethical activities, did not engage in religious disagreement and strife, helped the weak and the sick, cared for travelers, even for animals, and did not kill animals for food more than was necessary. The edicts were written in a Māghadi dialect, also a descendant of Sanskrit, and not in the sacred language itself. Some of the edicts found in the western parts of Aśoka's empire were even written in non-Indian languages, namely, in Aramaic and Greek, with the same messages as those of the Māghadi ones. Evidently, this was an attempt at a moral and peaceful crusade to his western neighbors, many of whom spoke and wrote Greek, as well as Aramaic, the lingua franca of the Persian Empire. While multilingualism and multiliteralism was indeed widespread in the Persian Empire, employed mainly for administrative use (the Behistun multilingual inscription has a political message, though it refers piously to Ahuramazda), Emperor Aśoka in his multilingual efforts expresses most of all a missionary zeal. There is no evidence that writing was used for administration in the Aśokan Empire, but this of course cannot be ruled out. But it is in accordance with the fact that few administrative records from Indian history before the second millennium CE are extant, though the religious literature (including the oral "literature") is enormous.

Apart from the Greek and Aramaic writing systems used for the edicts, the newly devised Indian system of writing was made on an initiative during Aśoka's reign, but we do not know anything about the details of this process. However, the system seems to have been rather autonomously devised, the so-called *Karoṣṭhī* syllabic writing has some similarities with the Aramaic, especially in a few of the syllables, and the fact that it is written from right to left, as other Semitic alphabets. But it is mainly an Indian invention, as is also the *Brāhmī* writing system, also syllabic and written from left to right and maybe devised to better fit the structure of Sanskrit phonology, as formulated by the Indian grammarians, as *Pāṇini*. The origin of writing in India, and also the concomitant literal multilingualism, seems to have originated with a religious purpose, at least this is our earliest evidence, but evidently the art of writing with its syllabic style was inspired from the West.[3]

Thus, writing in India is intimately connected with Buddhism, and Buddhism exploited the "new" technology fully to promulgate their religion and to build the institutions that were necessary for housing the learned and to develop the routines of copying the sacred literature, in particular from the first centuries CE on. Recent finds from Afghanistan and Pakistan, as well as those from Central Asia in the 1920s and 1930s have provided an insight into the old writing technologies in India. The oldest manuscript found so far is probably from the last century BCE and quite a number of extant manuscript fragments are dated from the first, second and third centuries. Extant manuscript materials after this period are fairly rich. The writing materials, as extant in the finds, are mostly palm leaf, which was used mostly in the southern areas, while in the north west birch bark became the most popular material on which to write the sacred literature, gradually supplanting

[3] For the Indian literacy developing under these circumstances, see (Hinüber 1990), and for the writing systems of Kharoṣṭhī and Brāhmī—the last of which was the precursor of writing systems all over South Asia, including Tibetan—see (Bright and Daniels 1996, 371ff.) and (Salomon et al. 1999). For the inscriptions and their context, see (Falk 2006).

the palm leaf. There are also some instances of writing on vellum; the ink was made of soot and water and has proven to be very durable. It has been preserved until today as it became petrified over the years.[4]

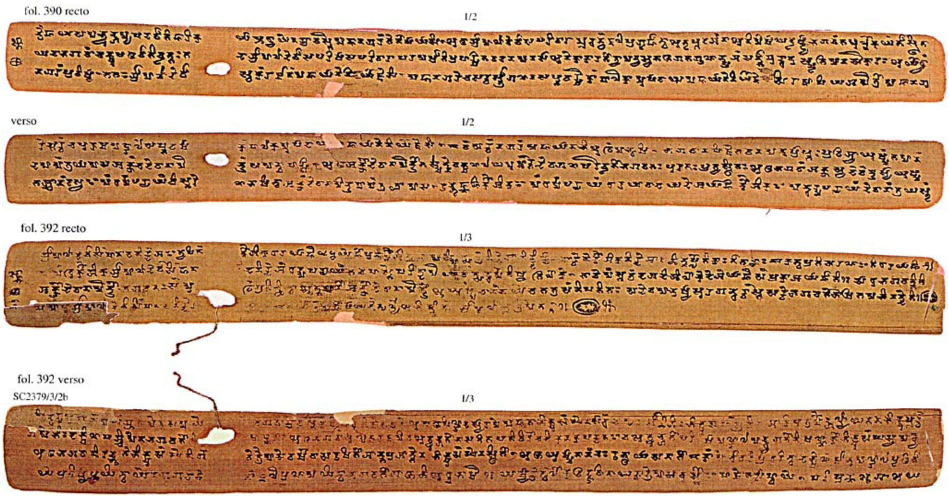

Figure 10.1: Palm leaf Mahāyāna manuscript from Bamiyan, ca. 500 CE, Schøyen Collection.

10.4 The Text, the Image of the Buddha and the Community of Monks: The Historical Continuity of Buddhism

The text gained a prominent position in all Buddhist traditions and was even portrayed as the "body" of the Buddha. Throughout most of its history, Buddhism, being thus text and knowledge based rather than cult and faith based, fostered disciplines of knowledge, and even intellectuality. In this way, the *tripiṭaka,* "the three baskets," as the Buddhist canonical scriptures are called, contain the *dharma,* the "law," or the Buddhist teachings in three collections:

1. Buddha's speeches (*sūtra*)
2. the monastic rules (*vinaya*)
3. the philosophic and systematic commentaries (*abhidharma*).

Under these three ideal collections the various canons were established by the diverse sects and branches of Buddhism resulting from doctrinal divisions, as well as by new collections created by translations throughout its history and Pan-Asian

[4]See (Salomon et al. 1999; Allon and Braarvig 2000; Berkwitz et al. 2009; Braarvig 2009); see also (Harrison and Hartmann forthcoming).

diffusion. The *credo* of Buddhism, the "Three Jewels" (*triratna*), by adherence to which the Buddhist becomes a Buddhist, is the following:

> I find my refuge in the Buddha, I find my refuge in the Teaching (*dharma*), I find my refuge in the Monastic Community (*saṃgha*).

These three, the Buddha image in its various aesthetic formulations, the canonical scriptures in its different linguistic forms, and the monastic community as the social expression of the Buddhist doctrine and always the keeper of Buddhist tradition, represent in fact very much what Buddhism historically amounts to in its origin as well in its diffusion.

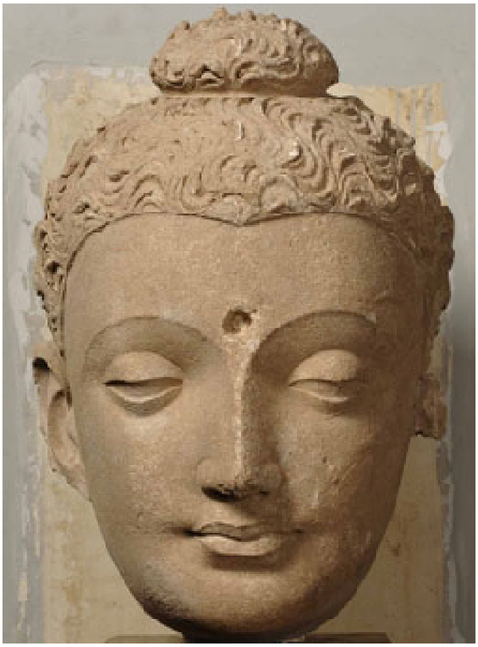

Figure 10.2: Stucco Gandhara head of the Buddha, second to third century CE.

The Buddha, as represented in images and cultic implements, has throughout Buddhist history created industries and crafts. In fact, the very beginning of Indian art history is connected with Buddhism; the Brahmanical tradition was not interested in images for the same reasons that they were not interested in writing. However, the Gandhāran art from the beginning of the first millennium CE was definitely also influenced by Greek styles of sculpture, one of the rather obvious influences of Greek culture on India. At the same time, another school of art, that of Mathura, created a style much less influenced by Greek art, a more distinct

Indian style. The historical relations between the two schools are not clear, and there are also examples of Indian art before these two main schools of Buddhist art, but these too are not older than the first century CE. The iconography arising out of this early Buddhist art created, as illustrated in Buddhist literature, the iconographic archetypes that with historical and regional variations became the formalized standards and concepts for representing the images of the Buddha and his environment throughout East-Asia, and unfolded in China and East-Asia, as well as in Tibet and Central-Asia. The aesthetic tone and the techniques of the production of images and paintings changed, but the earliest concepts as laid down by early Buddhist literature would remain the same. Because of the aesthetic differences, it is sometimes difficult to see that Japanese Buddhist art builds upon the same concepts as that, for example, of Tibet, but to a great degree this is the case. The same schemata are also very much part of Buddhist temple architecture: The old stūpas of India and Nepal, the Tibetan Chorten, the Chinese Pagoda or the Japanese Zen Garden, as well as the numerous grand Buddhist buildings spread around South-East Asia are all the microcosmoi of the general Buddhist cosmological systems, gaining its standardization some time before our era. Thus, temple architecture represents a great degree of continuity, supported by the literature and imagery of common tradition, and inspired various traditions of architecture, building techniques, painting, production of stone images as well as metallurgy and other techniques of production.[5]

We will return to the literature of Buddhism, as literature remains the focus of continuity throughout Buddhist history, regarded as such also by the Buddhist traditions themselves. But we should not fail to mention the third "Jewel" of the Buddhist *credo*, that of the monastic community, the *saṃgha*. This was established using a particular codex of monastic rules, the *vinaya*, and as such also based upon a systematic literature fairly constant both historically and geographically in the spread of Buddhism. Without the monastic community, it would seem that Buddhism would not present such an extensive historical and cultural continuity—this is also in fact in accordance with the Buddhist scriptures themselves. From the eleventh century on, wherever the efficient Muslim armies advanced in India, the great institutions of Buddhism were destroyed, and with them Buddhism itself. Without the strong monastic institutions of later Buddhism—almost a kind of university—and without the active sponsorship of the authorities, Buddhism, as a learned tradition, died out in India. It did not survive among the people in the traditional simple rural communities with their rituals and oral traditions, as did the Hindu traditions, notwithstanding the Muslim overlordship. But new Buddhist institutions were built in other places where Buddhism took root, both in the southern and northern traditions. Their loyal body of men, and to a lesser

[5]The classic for Silk Road diffusion is (Stein 1921); a further bibliography can be found in (Bopearachchi and Errington 2000). The classic documentation of Tibetan art is (Tucchi 1949); more recent works with bibliographies are (Rhie and Thurman 1991; Singer and Denwood 1997; Whitfield and Sims-Williams 2004; Bräutigam et al. 2006; Pande 2006; Skilling 2009). On the diffusion of architectural plans from India, see (Bunce 2002); see also (Franz 1978).

extent women, having vowed not to marry or transgress any rules, remained close to those in political power in all the places throughout East and South Asia where Buddhism became part of society. It seems that the monastic communities of Buddhism to some extent took over the institutions of eunuchs, who were also a class of persons purposely designed to be loyal to imperial power, particularly in China. We are thus able to say that the conceptual schemes of Buddhism also manifest themselves to a high degree in a social field of knowledge, and contributed rules and traditions for certain types of social organization. Though the *saṃgha* was originally conceptualized as a community for those seeking to practice the "way" of the Buddha, for individuals not engaging in politics, the monastic communities nevertheless became politically important: under Emperor Aśoka factions of the monastic community were already vying for imperial privileges and economic support. This has been a basic theme throughout the various traditions of Buddhism, and in the first or second century CE in the great split into the Mahāyāna, (the great way) and the Hīnayāna, (the small, or petty, way) as the adherents of Mahāyāna would call it, criticism of a corrupt and greedy monastic community was a central theme. In Tibet, the monastic community, with its effective organization and able candidates for office, also developed into the main political power and ruled Tibet for almost a thousand years. The *saṃgha* never developed politically in other countries of the East to the extent it did in Tibet, but it was always close to the political institutions, notwithstanding the monastic rule that monks should not engage in politics.

10.5 The Diffusion of Buddhist Dogmas, Rules and Conceptual Schemes by Narratives and Motifs

Another conceptual framework for maintaining the historical continuity of Buddhism was expressed in the literature of the *Jātakas,* (the life stories). These depicted the life, but most of all the previous lives of the Buddha, and featured moral stories for educating the lay communities. This class of Buddhist scriptures most of all illustrates the workings of karma: how any action done since "beginningless time," may "mature" into any situation at a much later time. The consequence of this dogma is that what we are and what we experience is always determined by our earlier actions. Thus, the individual has complete responsibility for whatever he may encounter in life, this being the favorite "most logical" theodicy of Max Weber. The Buddha remembers all of his lives and recognizes everyone he has encountered in previous lives, so as to help him free himself and others from the burden of earlier sins and actions. Thus, any monastic rule to protect against a particular sin or any rule on how to behave as monk would be supported by such a story. In this way, a sizable and flowery collection of tales and motifs, generated from the general stock of Indian and even global motifs, formed part of the body of monastic rules, the Vinaya. However, throughout the history of Buddhism the Jātakas were always a great source of Buddhist poetry and storytelling: entertainment as education for the lay and even the monastic communities. Beside the philosophical and learned tradition of Buddhism, creating and spreading learned communities, these collections of stories provided another strand of transfer of knowledge in Buddhism. This popularized form of the Buddhist teachings were set in a field of knowledge accessible not only to the learned, and were widely diffused by means of tales and motifs. They were, however, still based on a formalized literature which was dealt with in the monastic institutions where these edifying stories were organized, written, translated, printed, illustrated and finally propagated.[6]

This brings us to a particular mode of transfer of knowledge motifs, which are part of all traditions of Buddhism, but by no means confined to canonized literatures and monastic administration. Conceptual schemes were spread by tales and motifs, orally and often accidentally, along trade routes like the Silk Road, where Buddhism traveled, along with several other religious systems like Manichaeism, Nestorian Christianity, and surely many arts and crafts belonging both to religious and to more pragmatic businesses, as well as diplomatic contact, or even by hostile contact brought about by spying and war. We find that Buddhism was spread systematically—by translators and learned teachers like the well-known historical personalities who brought Buddhism to China, Tibet and across East-Asia. But the conceptual systems of Buddhism also spread in more informal ways, by diffusion of its motifs, creating fields of knowledge that are not so easily defined historically and which are sometimes completely isolated from the context in which they arose. One example of this is the diffusion of the biography of the Buddha. This was filtered to the West by means of Manichean and Arab versions, was translated into Latin in 1047, and became a legend of the two Christian martyrs Josaphat and Barlaam, even ending up in early Norse Christian literature as a pious Christian legend (Rindal 1980).

In this case, the story can be traced historically by its gradual translation, but motifs of course also diffuse beyond such literary activities by oral means, and, certainly, the "missing links" may be difficult to find. This, however, should not prevent us from investigating processes of global diffusion as possible and probable scenarios of the globalization of knowledge. When the conditions of diffusion are there, and the similarity of conceptual regimes are present in different locations, they should certainly be objects of investigation in the perspective of globalization processes. A case of this might be the Buddhist concept of hell and infernal punishment. The Buddhist sūtras, and not the least the Jātaka stories, depict existence as endless chains of reincarnations throughout the Buddhist cosmos, consisting of human existence, beside the divine, the animal, the hellish, and the existence of wandering spirits. Hell is a place where judgments are passed on the sinners in a way very similar to the hell of Christianity. However, there are good arguments that the Buddhist hells antedate the Christian by several

[6] On a systematical treatment of the motifs in the Jātakas, see (Grey 2000). The scholarly literature on the *vinaya* is voluminous, see (Heirman and Bumbacher 2007).

hundred years, well before the beginning of our era: the Christian images of hell are only found in the third and fourth century CE, with their origin in Egypt, where also the monastic Christian institutions have their origin in about the same period. One may thus argue, though it remains difficult to prove, that Christian belief in hell may be influenced by Buddhist ideas of the same, and that even the monastic idea may have had a similar inspiration. Indeed, the monastic life that for several hundred years had been practiced in India has scarcely any antecedents in the Mediterranean world.[7] This argument is plausible because of the extended trade between Egypt and India in the period, as evidenced on both sides. It is very difficult to prove, though, as there is no detailed and concrete evidence of this diffusion of conceptual and organizational schemes. But, it is also very difficult to disprove, as the comparative evidence is fairly strong: the possibility for communication between the two cultures is a historical fact and the phenomena are definitely earlier in India than in areas of early Christianity.

That diffusion took place between the Mediterranean world and India, and vice versa, in a long perspective of time, along the Silk Road as well as along the sea routes, is definitely the case, even though the evidence to support this communication is rather scant. During the Persian empires, however, there was a developed multilingualism that must have facilitated communication between the areas in question. Such circumstances were also prevalent after Alexander's conquests, which enabled and even facilitated cultural communication between the West and the East, as is amply exemplified in the Greek-influenced Gandhāra art. Greek kingdoms in the East influenced culture in the North East, thus Bactrian documents were written using the Greek alphabet, and ample coin evidence demonstrates the practice of homage to Greek gods as well as to Buddhist and Hindu religious figures. Motifs, however, are traceable as impressions on coins and in the form of arts and other religious artifacts. Astrology, however, is so far the only example of a complex system of knowledge that was translated from the medium of Greek to Sanskrit—the systems are fairly similar and one finds Greek loanwords in Indian astrology. The Hellenistic Seleucid king Antiochus II (286–246 BCE) is mentioned in two of Aśoka's edicts: one describes Aśoka's missionary activities, the other also communicates the spread of medicine as a pious act. The Greek envoy of Seleucus Nicator to Candragupta's and Bindusāra's courts between 302 and 291 BCE, Megasthenes, wrote a work in Greek with the name *Indica.* We know this work only from fragments, but it did not express a too profound understanding of Indian life. It seems that Megasthenes received most of his information from interpreters, though he seems to have stayed in India for a prolonged period. But, much quoted, his description had a great impact on the *perception* of India in antiquity. Antiochus I was also in contact with Bindusāra, as diplomatic correspondence between the Indian imperial court and the Greeks demonstrates, also

[7]See (Braarvig 2009); cf. (Warmington 1928).

giving evidence to the fact that the Indians were not only interested in trade and war with their neighbors in the west, but also in Greek philosophy.[8]

Rather than a vague collection of motifs, however, Buddhism was a fairly well-defined conceptual system generated from the Sanskrit language and its dialect Pāli, as well as from other Indic dialects as mentioned above, and as such connected to the general Indian learning in the centuries before and after the beginning of the Christian era. Buddhist literature can be seen as a series of attempts to create a consistent system of thinking, reflected in the several attempts by a number of sects to create a literature to be the canon of "true" Buddhism. One of these attempts was the formalization of a voluminous literature of Mahāyāna Buddhism, which originated in the first two centuries CE. This form of Buddhism seems most of all to be a literary expression rather than a cultic movement, and the attempts to place it geographically and institutionally have so far not been very successful, though its cultural context seems to be the fairly affluent city-cultures in India of the period. However, this literature, characterized as a forgery by earlier mainstream Buddhism, still came to be the basis of Buddhism in its "northern" form. Its concepts were in several respects different from mainstream Buddhism: it represented a philosophical, religious, social and probably political reaction against earlier Buddhism by putting even more emphasis on the doctrines of relativity, emptiness, deconstruction and selflessness, and the endlessness of innumerable universes, many of them with residing Buddhas, like those of "Endless Light" and "Endless Life," whose figures would gain great influence in the northern and eastern spread of Buddhism. Further, this literature emphasized a radical altruistic morality with arguments, or rather sophisms, like the following: "it is absurd to try to liberate oneself when there is no self." Thus, Mahāyāna literature promoted the lay life on the model of the earlier lives of the Buddha as depicted in the Jātakas, being highly critical of what they styled the corrupt and escapist monastic life.

However, the Mahāyāna literature did not really change the vocabulary of traditional Buddhism; it rather reinterpreted the old words to suit their purposes. So, notwithstanding the change of ideology, the terminology of Buddhism retained its basic structure with a fairly stable lexicon, an important fact in our attempt to understand the continuities and discontinuities of this conceptual system as undergoing translations to other linguistic environments and its ensuing transformations.

10.6 The Silk Road and the Spread of Buddhism to China and East Asia

The Indo-Scythian, or Kuṣāna, emperor of India, Kaniṣka, who ruled in the first and/or second century CE is reported by historical sources to have called a council of Buddhist scholars to conduct a debate on what is the true teaching of the

[8] On Greek influence in India, see (Karttunen 1997; Lamotte 1988, 243ff. and 407ff.). On cultural communication between India and Greece, and the lack of such, see (Halbfass 1988).

Buddha, since he found there was such a great number of books with diverging opinions. This is exactly the period when the origin of Mahāyāna Buddhism is placed, and, being from the north-west, the areas of his dynasty played an important role in communicating Buddhism to the East, to Central Asia and to China, from the north-western areas of Gandhāra. Many of the translators of Buddhist texts, apart from several Indian scholars participating in this effort in the third and fourth centuries, are termed 月支 *Yuèzhī*, as the Chinese called the Kuṣāna, and probably also other peoples of Persian or Scythian origin, like the Tokharians. These peoples lived in highly multilingual environments and in areas with great mobility, such as along the Silk Road in its Buddhist centers of Bamiyan, Turfan, Dunhuang and so forth. Translations of Buddhist texts took place not only into Chinese, but also into Khotanese, Tokharian, Old Turkish and other languages. It was in these languages that a translation idiom for Buddhist terminology was created along with the borrowing of Indian script systems and writing styles.

The earliest Chinese translations of Buddhist texts at the end of the second century CE are still characterized by the lack of a systematic Chinese terminology for Buddhist terms; the words coined to reproduce Buddhist concepts naturally build on the classical Chinese semantic world, which was not always suited for representing the foreign system of concepts. Thus, during the second century, but especially from the translations of the very productive Indian Dharmarakṣa, who lived in China around 300 CE, a terminology was created in Chinese that was better suited for representing Buddhist ideas. One may surmise that the general Chinese reader of these texts, uninitiated into the Buddhist conceptual world, would still read with a classical Chinese conceptual background, and at times would have great difficulty grasping the actual meaning of the texts. However, with the "Buddhist Conquest of China," as Eric Zürcher (1959) terms it, a Buddhist discourse developed that indeed gives evidence to the fact that the more sophisticated Buddhist texts were understood by the Chinese, at least by the specialists. Over the centuries, the systematic terminological work initiated by Dharmarakṣa and to some extent his predecessors, like An Shigao, 安世高, Zhi Qian, 支謙, and Lokakṣema in the second and third centuries (Nattier 2008), was continued by the famous Indian translator Kumārajīva (CE 344–409) among others, and then by the Indian scholar Paramārtha (CE 499–569), who greatly influenced Chinese Buddhist terminology. Also the legendary traveler to India, Xuánzàng, 玄奘, in the seventh century (CE 600–664), brought the art of translating from Sanskrit into Chinese to its highest perfection. Xuánzàng was also one of the travelers to India who wrote a history of Buddhism associated with the places he visited whilst collecting original manuscripts as materials for his translations. With some exceptions, the later translations into Chinese in the eleventh century amount to little more than revisions of earlier translations, including some very inaccurate translations from the original where the Chinese style has become much more important than conveying the technical terms of Buddhist thinking.[9]

In this way, over the centuries a Chinese idiom of Buddhism was developed, an idiom that to some extent became a religious lingua franca. This style of Chinese was also employed by another religion that entered China via the Silk Road, namely Manichaeism, on which numerous texts in Chinese have been preserved. Thus, Manichaeism in its Chinese form became a mixture of the Manichean and Buddhist conceptual schemes (Lieu 1998). What is surprising, though, is that few systematic works that could have aided the translators are known to exist; there are no grammars, no dictionaries and few lists of technical terms in Chinese before the Tang Dynasty (seventh–ninth century CE), and this despite the great Chinese interest in archives, in particular, catalogues of Buddhist scriptures. Thus, there is a lack of standardization of terminology in Chinese Buddhism, even though certain terms are defined by their repetitive use by the translators, as those mentioned. The technical terms appear in the texts themselves, but not in independent systematic works: the translations of certain influential texts took on the role of terminological standards. Indian logic was a discipline that entered Chinese thinking as a corollary of Buddhist translations, but little Sanskrit grammar and lexicography had any historical influence on China, even though the religious, psychological and philosophical conceptual systems of Buddhism were continued in China independent of their country of origin. Thus, the first known lexicon 翻梵語, *Fānfànyǔ*, before 587 CE, is not so valuable for Buddhist terminology since it is almost exclusively concerned with *names*: various names of the Buddha, place names, names of various men, plants and so forth. (Chandra 2007). The most famous lexicon, however, is from the Tang Dynasty, the 一切經音義, *Yiqiejingyinyi*, (A Lexicon of Sounds and Meanings in the Tripiṭaka), by Hui Lin, 慧琳, 737–820 CE. This lexicon is also not very useful for Buddhist terminology as it is mostly concerned with the pronunciation of the Chinese expressions rather than their semantic content.

The Chinese Buddhist canonical scriptures were edited many times during several imperial dynasties, and the translations were always dated according to the reign of the emperor under which they were produced. In this way, the discipline of cataloguing and dating texts and collections was well taken care of in China, whereas this was almost non-existent in India. From China, the canonical scriptures were also spread further throughout East-Asia to Korea, Japan and Vietnam, and in general also became the canonical scriptures of these areas. Indian writing systems were adopted in the Far East, but had limited influence as in general they were not used as a tool for writing, but rather for decorative purposes and incantations. This is in great contrast to the diffusion of the Indian writing

[9] For traditional Chinese views on translations, their methodologies and styles, see (Cheung 2006), which in a sense continues the pioneering work (Fuchs 1930). Fuchs is the first to describe the various roles of the scholars, interpreters, writers and so forth, involved in the process of translating.

systems to South and South-East Asian countries, which is easily explained by the fact that the Chinese had had their own system of writing for more than a thousand years. If words had a particular important meaning or authority, however, like the Buddha names or the sacred formula, then transcriptions of Indian words were sometimes employed for Chinese translations, with the Sanskrit word written with Chinese characters as syllables. Examples are 佛陀 *fótuó* for Buddha and 涅槃 *nièpán* for nirvāṇa, but usually all words were translated into the proper Chinese logographics, representing the concepts by Chinese traditional means.[10]

Even though the Buddhist texts may have appeared difficult to understand for the Chinese, it is still quite clear that their language and conceptual schemes were diffused throughout East-Asian culture and thinking: the modern Chinese, Korean and Japanese languages still abound in Buddhist words and expressions.

10.7 The Spread of Buddhism to Tibet

Figure 10.3: Samye Monastery, first Tibetan monastery, eighth century CE, built on a Buddhist maṇḍala plan.

The diffusion of the Buddhist conceptual world into Tibetan culture, however, takes place to an even greater degree than is the case with China and East Asia.

[10]The principles of the use of transliterations instead of translations were set down by Xuánzàng, see (Cheung 2006, 157): *dhāraṇī*, 它羅尼, *tuóluóní* (sacred formula); *bhagavān*, 簿珈 梵, *bójiāfàn* (the Lord); *jambu*, 閻俘樹, *yánfúshù* (name of India); *anubodhi*, 阿耨菩提, *ānòupútí* (Awakening), *prajñā*, 般若, *bànruó*, meaning "wisdom" is also translated as 智慧, *zhìhuì*, but Xuánzàng says that this has "less authority."

While the Buddhist conceptual systems met a well-developed classical culture with a very broad semantic horizon in China, the Tibetan language that was the medium for receiving the much more complex Buddhist conceptual world was, as far as we know, a simple language with no writing system for literature or for administration; it was a language spoken by nomadic people focused on military activities. When King Songtsen Gampo, as mentioned above, decided to import Buddhism into Tibet, he ordered at the same time that a system of writing be made on the basis of the Indian scripts of the day and the phonological system that pertained to it. His successor, Thri Songdetsen, adopted Buddhism in 762, and, after his conquest of the Chinese capital of Changan in 763, built the first great monastery of Tibet, Samye, in 779. After conquering the town of Dunhuang, north of Tibet, in the 780s,[11] King Thri Songdetsen invited the Chinese Zen-master, Moheyan, and the Indian scholar Kamalaśīla, for a debate at Samye so that the king could decide whether he should import Buddhism from India or from China. The Indian scholar is said to have won the debate, and, according to the Tibetan historical records, the king decided on India. Under his successor, Thri Desongtsen (CE 804–815), a systematic Tibetan lexicography and grammatical science was developed on the basis of the Indian Pāṇinean tradition, and by royal decree only the established standards of Sanskrit-Tibetan equivalents were to be employed in the process of translating terminology and concepts from the Sanskrit to the rather simple linguistic environment of Tibet. Many of these grammatical and lexicographical handbooks are extant, giving evidence to a remarkable intellectual effort by the Tibetan translators.[12]

Thus, the rather simple language of pre-Buddhist Tibet was molded in the form of Sanskrit Buddhist semantics, syntax and grammatical forms, a process that completely changed the language and conceptual world of Tibet, as well as for the most part its material, social and political culture. Compared to the rather unsystematic way in which Buddhism was introduced to China, mostly by individual activities and initiatives, the Tibetan case of knowledge transfer represents the systematic change of a simple culture into a completely new, and much more complex conceptual and cultural scheme, the corollary of which was the translation of many fields of knowledge, but also the creation of new fields of knowledge as the Tibetans developed the decaying Indian Buddhist culture into their own tradition and implemented it under new conditions. Thus, all the sciences connected with Buddhism—philosophy, psychology, logic, rhetoric, mnemotechnics, grammar, lexicography, writing, calligraphy, architecture, painting and medicine—were introduced to Tibet in this process of systematic cultural import, and developed further, while in India Buddhism died out. In this context, we may mention in particular the xylographic printing processes and paper making which developed in Tibet from the fourteenth century on. Despite being influenced by Chinese printing, there was widespread use of ink and handwriting in Tibet: printed Buddhist texts

[11] This is why the oldest extant Tibetan Buddhist manuscripts were found here.

[12] See (Simonsson 1957; Ishikawa 1990; Verhagen 1994); in general (Kapstein 2000).

were never found in areas where the Indian style of text production prevailed.[13] However, xylographic printing existed for a long time alongside ordinary handwritten manuscripts: the first Tibetan manuscripts we know of, from Dunhuang, were indeed handwritten. For the copying of the large-scale canonical scriptures of the Kanjur and Tanjur (Buddhas word and their commentaries), however, the technique of carving mirrored text into wooden printing plates and smearing them with ink, so as to imprint the wooden block on the paper, was developed into a sizable industry in Tibet along with the preparation of paper. A number of editions of important texts were made, and, notwithstanding the more efficient technique of copying by way of the xylographic preparation of whole plates, the resources used for book production were enormous. But given the great respect for religious values, and even for knowledge, the means for this activity was raised most often from the aristocracy, royalty and rich monasteries. For the production of a particular edition of the Tibetan sacred texts support was even given by the Manchu emperor Qianlong, 乾隆帝, ruler of the Qing dynasty 1735–1775.

The fields of knowledge of Buddhism were rather the *trivium* of the Western Middle Ages, that is grammar, logic and rhetoric. These were much more important than the *quadrivium*, that is, mathematics, music, grammar and astronomy, in much the same way as in the Middle Ages themselves. So, even though Buddhism may have been part of the thinking connected to the origin of the mathematical idea of *nihil*, or zero, we find nothing of mathematical interest in the Buddhist canonical literature, notwithstanding the interest in endlessness and huge numbers, which was rather employed in a metaphorical, and not in an exact way. However, logic became an important discipline as a corollary of Buddhist philosophy, especially that of the Mahāyāna, which attempts to reduce all final intellectual truth and doctrine *ad absurdum.* Rhetoric also finds its place in this picture, and, as mentioned before, in grammar. The philosophy and psychology of universal flux, intellectual deconstruction and emptiness was the main concern of Buddhism, and not how to manipulate matter—thus old Tibet had no more sophisticated machinery than the water wheel. And the historical Chinese attempts at natural science were never influenced by Buddhism, even though there are good arguments that historically Chinese logic is a Buddhist discipline.[14]

There is another important aspect of Indian knowledge transfer by Buddhism worth mentioning, namely *āyurvedic* medicine.[15] This medical tradition spread throughout South Asia over the centuries as part of the general Indianization and

[13] On the first known printed text in China, CE 868, the Buddhist text *Vajracchedikā*, also found in Dunhuang, see (Whitfield and Sims-Williams 2004). On writing in Tibet, see (Schaeffer 2009).

[14] In its origin Buddhist logic is mainly connected to discussions with the Brahmanical traditions, and as such in many cases is more aptly described as rhetoric or even "anti-logic," very much in line with modern "deconstructionism." In Tibet and China, it continued to treat problems of disagreement within the tradition of Buddhism itself. For India, see (Potter 1977); Tibet: (Kapstein 2000, 85ff.); China: (Needham and Harbsmeier 1998).

[15] See now, on Indian medicine in general, (Meulenbeld 2002), on Vāgbhaṭa, see vol. IA, 597ff. The dating of Vāgbhaṭa's work is much discussed, but the main opinions place him in the late sixth or the early seventh century.

it is not always easy to say whether it spread particularly as part of "Buddhist culture." A Chinese traveler to India, 義淨, Yijing, probably refers in his chronicles to the *Aṣṭāṅgahṛdayasaṃhitā* (The Heart of the Eight Limbs of Medicine), an authoritative work on the various medicinal disciplines of the *āyurvedic* tradition composed by the celebrated figure Vāgbhaṭa, who seems at least to have had sympathies for Buddhism. Though the *āyurvedic* tradition may not have had much influence in China, its influence is very clear in the case of the spread of Buddhism to Tibet and subsequently to Mongolia, where several works on Indian medicine, among them the mentioned *Aṣṭāṅgahṛdayasaṃhitā* as well as the *Aṣṭāṅgasaṃgraha*, were translated into Tibetan in the the early eleventh century, along with Indian commentaries, and became the one of the foundations for the development of the rich Tibetan medical tradition. Other medical works from the same Indian tradition formed part of the enormous Tibetan translation effort of Buddhist literature and culture.[16]

10.8 Conclusions

What is said above merely scratches at the surface of the conceptual world of Buddhism and its application in some fields of knowledge. For the purpose of understanding how such knowledge is globalized, we have touched upon some modes of its diffusion as well.

We see that Buddhism is spread most of all through its literature, on which great emphasis is placed. In Tibet, this literature was translated in a highly systematical way, but in China to a lesser degree. Still, the Buddhist canonical scriptures as established on the basis of these translations became enormously influential throughout East-Asia for very long periods of time. We must presume that these texts were mostly interpreted in a "correct" way by their translators, who recreated the conceptual systems underlying the Sanskrit languages in the new linguistic media of Chinese, Tibetan, and so on, since these concepts are well recognizable in the receiving languages. It is unclear, however, whether a concept transferred to a completely different cultural background retains its original content; a basic problem that is connected with all kinds of translations. And indeed, many of the translations of Buddhist texts, especially into Chinese, may be characterized as rather inaccurate and have often lost some of the conceptual subtleties present in their Sanskrit form. However, if one analyses the Tibetan translations of Buddhist terms, these are found to be considerably more accurate than the Chinese translations. This is probably explained by the fact that the Tibetan written language was created to translate exactly these Buddhist texts and to express exactly this conceptual system of Buddhism; the Tibetan language

[16] See (Meulenbeld 2002, vol. 1A, 656) for references to the discussion on the classical text on Tibetan medicine, the *rGyud bźi* and Vāgbhaṭa's works. Tibetan medicine is also influenced by other traditions, but its early history remains unclear.

was prepared with grammatical structures that could accommodate the Buddhist Sanskrit language and its semantic contents.

Buddhism, as described above, was also spread by the social system of its monastic community as well as by the crafts employed in the propagation of the Buddhist faith: those connected to the writing of sacred texts and to the art depicting the Buddhist motifs, arts and crafts that were developed further during contact with counterparts in the receiving cultures. However, there are also examples where Buddhist motifs have been communicated without being recognized as such in the receiving cultures, as in the legend of Josaphat and Barlaam. Another possible example of diffusion of Buddhism, which is difficult to prove, though, is that of monastic life and the idea of hell. This last example pinpoints the difficulty one may encounter in the description of the globalization of knowledge, since similarities in fields of knowledge may be found, but whether these are a result of diffusion or independent ideas, is often hard to decide. Buddhism, though, as a conceptual and cultural system exemplifies a number of types of diffusion, spanning from historically well-documented examples to those that can only with hesitation be proposed as diffusion of knowledge.

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Chapter 11
The Transmission of Scientific Knowledge from Europe to China in the Early Modern Period

Matthias Schemmel

11.1 The Global Spread of Modern Science

At the beginning of the twenty-first century, modern science is clearly global. It originated in early modern Europe and spread from there all over the world, either through the migration of people who brought it with their culture, as is the case for America and Australia, or through its adoption by non-European cultures, as is the case for China and Japan.[1] It is true that even today not all countries have the same means to produce scientific knowledge or to participate in global scientific communication. It is also true that national science politics and the decisions of local communities have an impact on the subject-matter of scientific research. But on a global scale there are shared bodies of scientific knowledge, shared scientific practices and shared criteria for the evaluation of scientific results, so that one may speak of a global culture of science. In particular, science is not expected to depend on the characteristics of one particular modern culture, such as the native language or the religious beliefs of those doing science.

It is this aspect of the universality of modern science, its compatibility with a wide variety of cultural backgrounds, together with the idea that science produces true statements about the world and the obvious usefulness of science for developing advanced technology, that may lead to the belief that the spread of modern science to non-European cultures was a matter of course, a simple process of adoption, possibly evolving at epidemic speed: cultures once infected by modern science and its merits could not but adopt it.

The example of China shows that this is not the case. In the seventeenth and early eighteenth centuries, just at the time when the early modern Scientific Revolution was taking place in Europe, the worldwide missionary efforts of the Jesuits brought Chinese society into direct contact with European science. Yet, modern science did not take root in China and in the first half of the eighteenth century, the transmission of European scientific knowledge to China came to a virtual halt. It gained new impetus only in the second half of the nineteenth

[1] To say that modern science originated in early modern Europe should not be taken as a denial of its non-European roots. For the multi-millennial history of knowledge transmission throughout Eurasia and northern Africa, see survey chapter 9.

century when the arrival of protestant missionaries led to a second wave of science transmission under drastically changed political conditions. But it was not before decades of intellectual, social and political struggle for its reorganization that the Chinese knowledge system attained a new stable structure that incorporated modern science.

This chapter will discuss the first wave of transmission of European scientific knowledge to China in the seventeenth and early eighteenth centuries.[2] After a very brief overview of science and technology in China prior to the arrival of the Jesuits (section 11.2), the chapter discusses how the Jesuit enterprise in China brought about the transfer of European scientific knowledge (section 11.3). The religious and political contexts that made this knowledge transfer possible imposed at the same time severe constraints on it (section 11.4). The result was a selective integration of European knowledge into the Chinese knowledge system, without, however, profoundly changing, let alone revolutionizing it (section 11.5), while the structure and content of the transferred knowledge was transformed in a process of assimilation to the Chinese knowledge traditions and institutions (section 11.6). The chapter concludes with a summary interpretation of the transmission of scientific knowledge from Europe to China in the early modern period in terms of the encounter of two separate systems of knowledge (section 11.7).

11.2 Science and Technology in China Before the Jesuit Intervention

To understand the Chinese reception of European science, it is crucial to take into account the existence of Chinese indigenous science. The term 'indigenous' should not suggest that Chinese science before the Jesuit intervention had developed in isolation. Just like early modern European science, it was the result of a multi-millennial history of knowledge transmission throughout the Eurasian and (northern) African continents.[3] But direct intellectual exchange between the western and the eastern extremes of the Eurasian continent was scarce, so that the arrival of the Jesuits in China had the potential to become a major event in their respective intellectual histories.

In identifying the potential and actual consequences of this cultural encounter, it is important to take into account that scientific knowledge never exists in isolation but is always part of a larger system of knowledge with which it interacts. In fact, the transmission of scientific knowledge—between cultures as well as within

[2] A broad account of the development of science in China under Western influence is given in (Elman 2005). Different perspectives on the early modern knowledge transfer from Europe to China are offered in (Jami 1999; Huang 2005). This chapter is not concerned with knowledge transmission in the opposite direction, i.e., from China to Europe, which constitutes a topic of its own.

[3] See the various contributions to Parts 1 and 2 of this volume. For examples from the multi-millennial transmission of knowledge in the mathematical sciences throughout the Eurasian continent, including China, see, e.g, (Høyrup 1989; Dold-Samplonius et al. 2002).

a culture from one generation to the next—presupposes a body of basic non-scientific knowledge that the originator and receiver share. No science textbook, even the most basic one, is comprehensible in itself. In the case of intercultural exchange this fact immediately raises the question of where the shared knowledge that makes communication possible comes from. Are there human universals that may account for the development of shared structures of knowledge in different cultures? Is the shared knowledge the result of earlier cultural exchanges? Is it the result of independent parallel developments? The answers to these questions may be different for different forms of knowledge. Thus, one may assume that certain aspects of the elementary knowledge acquired by any individual in the process of ontogenesis are universal owing to the fact that they are constructed in the context of the individual's interaction with a physical environment whose basic properties are largely culture-independent. Further, it is obvious that the acquirement of practical knowledge through dealing with technology presupposes the existence of corresponding technologies in the culture under consideration. The existence of these technologies may be due to their import from another culture, to independent invention, or to any possible graduation between these two extremes.

The question of the origin of theoretical knowledge structures that are shared across cultures requires the issue of independent development versus knowledge transfer to be addressed on several levels, since theoretical knowledge results from reflection upon other forms of knowledge in the context of (mostly literal) traditions of argumentation. Thus, besides the question of the origins of the knowledge reflected upon, there is the question of the conditions for the emergence of traditions of argumentation and the transformation of these traditions through contact with (initially) foreign theoretical traditions. In this context it is important to note that in different cultures similar constellations of practical and theoretical knowledge may develop independently. In fact, there appears to be a case of such independent parallel development in ancient Greece and China, where similar mechanical technologies brought about similar theoretical insights (Renn and Schemmel 2006). This shall be outlined briefly here.

Before the formulation of any explicit theories of mechanics, similar mechanical devices were used in China and the West. An example of such a device is the shoulder pole, which has two containers hanging at each end and which was kept in equilibrium when being carried on one shoulder. The use of this device is attested in Greece for the fifth century BCE and can be argued to have existed in China in the third century BCE (Damerow et al. 2006, 4), but it may be assumed that it was invented much earlier. The earliest known texts of theoretical mechanics in ancient Greece and ancient China, the Peripatetic *Mechanical Problems* and a couple of sections in the so-called *Mohist Canons* (*Mojing* 墨經), were written independently at about the same time, around 300 BCE. Both texts contain statements that may be considered as precursors of the law of the lever and that resulted from the reflection on practical activities such as balancing the shoulder pole. Thus, for instance, in free translation, one of the so-called Canons of the Mohists contains the following explanation:

> A beam: if you add a weight to its one side, [this side] will necessarily hang down. This is due to the effectiveness and the weight matching each other. Level both sides up with each other, then the base [i.e. the heavy side] is short and the tip is long.[4]

Likewise, the Peripatetic *Mechanical Problems* contains the statement:

> The further that which moves the load is away from the fulcrum, the more it moves the load.[5]

While there is in fact a common core of mechanical knowledge in the earliest theoretical accounts on mechanics in China and in the West, and even the social context of their emergence displays similarities (a politically highly fragmented cultural realm in which specific cultures of disputation had developed), the particular conditions of the origin and the later fate of these theoretical accounts were quite different. Thus, Peripatetic mechanics directly reflects the invention of the balance with unequal arms and its identification with mechanical devices such as the shoulder pole.[6] In China, the balance with unequal arms was used possibly as early as the time of the Jin 晉 dynasty (265–420 CE), but its oldest attestations do not reach back to the time of the Mohists.[7] What is more important, in Greece the incipient theory of mechanics quickly developed into a comprehensive body of theoretical knowledge, prototypically represented in its theoretical and practical aspects by the works of Archimedes and Heron respectively. In China, by contrast, the theoretical tradition of the Mohists was soon interrupted by the autocratic regime of the Qin 秦 dynasty (221–206 BCE) from which it never recovered. It was only after the Jesuits' intervention in Chinese history of science that the ancient Chinese mechanical heritage was rediscovered.

The Chinese tradition of practical mechanics and technology, however, continued and flourished. Many centuries before the arrival of the Jesuits, various Chinese technologies like those of agriculture, textile and paper production, book printing and water transport were highly advanced. As was the case for European technology until well into early modern times, the technological development had largely taken place without the reliance on any kind of theoretical knowledge.

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[4] "(衡)。加重於其一旁必捶，權重相若也。相衡，則本短標長。" Section B25b in (Graham 1978, 387). The translation given here is based on joint work of a project group at the Max Planck Institute for the History of Science with William G. Boltz.

[5] "ἀεὶ δὲ πλέον βάρος κινεῖ, ὅσῳ ἂν πλέον ἀφεστήκῃ τοῦ ὑπομοχλίου ὁ κινῶν τὸ βάρος." (Aristotle, *Mechanical Problems*), 850b14–16 (Aristotle 1936, 354), modified translation.

[6] A balance with unequal arms is explicitly mentioned in problem 20 of the *Mechanical Problems*. An earlier attestation of the use of balances with unequal arms in Greece is found in Aristophanes' play *Peace*, see (Damerow et al. 2002, 95).

[7] For a discussion of different assumed dates for the earliest occurrence of the balance with unequal arms in China, see (Guo 1993, 29–30; Renn and Schemmel 2000, in particular 22–23).

But while in Europe branches of the mathematical sciences developed that were concerned with resource saving technologies like simple machines, this was not the case in China, where the mathematical sciences were mostly concerned with astronomy, numerology and harmonics (Sivin 1977, xiii).

Traditional Chinese mathematical texts are mostly written in the form of problems and prescriptive rules for their solution. They contain solutions to intricate problems, for example, to what today would be called systems of linear equations. The tradition also includes what may be called geometrical problems, but there is no science of geometry in the deductive style of Euclid's *Elements*. To what extent the Chinese algorithms represent proofs implying a tacit foundation in deductive reasoning is a controversial issue.[8]

Chinese mathematics is often said to have been in decline for centuries before the arrival of the Jesuits.[9] Indeed, many classical works of Chinese mathematics, such as Liu Hui's 劉徽 (fl. 263 CE) comprehensive commentary to the *Jiuzhang suanshu* 九章算術 [*Nine Chapters on the Art of Calculation*], were no longer available, and the thirteenth-century tradition of algebra had become obsolete (Needham 1988, Vol. III, 51). Nevertheless, there was an active tradition of arithmetics well into the time of the Jesuits.

An influential text of the period under consideration is the *Suanfa tongzong* 算法統宗 [*General Source of Computational Methods*] of 1592, compiled by the merchant Cheng Dawei 程大位 (1533–1606), who was a devoted collector of arithmetical knowledge. Interestingly, there are indications of European influence in this text that hint at a transmission of knowledge predating the Jesuit mission,[10] possibly from the Portuguese settlement in Macao (Needham 1988, Vol. III, 148).

Throughout the history of imperial China, astronomy was predominantly calendrical science in the service of the imperial court. In certain periods the pursuit of astronomy outside the court was even prohibited. A wealth of records document an unbroken multi-millennial tradition of astronomical observations, including observations of sunspots, comets, novae and supernovae. The calculation of the calendar included the prediction of the positions of the sun, the moon and the five planets, as well as of rare events like eclipses. While the calendrical calculations were not based on geometrical models of the heavenly motions, there are Chinese sources documenting simple geometrical conceptions of these motions.[11] In the Mongolian Yuan 元 dynasty (1206–1368), an Islamic Astronomical Observatory was established in addition to the traditional Chinese one, which still existed in the seventeenth century. An influence of Islamic astronomy on the Chinese tradition is arguably visible in the field of astronomical instrumentation, as the prominent

[8]See, for instance, (Cullen 1995; Chemla 2005).

[9]See, for example, (Needham 1988, Vol. III, 209; Martzloff 1997, 19–20).

[10]Consider, for instance, the problems in vol. 4 of the *Suanfa tongzong*, which arguably reflect knowledge of the law of the lever.

[11]Geometrical conceptions of the celestial motions are evident, for example, in Shen Gua's 沉括 (1031–1095) *Mengxi bitan* 夢溪筆談 [*Brush Talks From Dream Brook*], chapters 7 and 8 on astronomy (*Xiang shu* 象數), see (Gua 1997). For a German translation, see (Kuo 1997).

example of Guo Shoujing's 郭守敬 (1231–1316) instruments reveals (though no originals are extant).[12]

Besides these predominantly quantitative sciences, there were qualitative discussions of physical phenomena like magnetism and optical phenomena, and rich traditions of what may be called medicine, alchemy, astrology and geomancy (not forgetting the huge differences in the European traditions of the same name). They mostly drew from a common pool of natural philosophic concepts such as yin 陰 and yang 陽, and the Five Processes (*Wu xing* 五行), (Sivin 1977, xiii).

11.3 How Scientific Knowledge Came to Be Transmitted by the Jesuits

In the seventeenth and early eighteenth centuries European scientific knowledge was transferred to China almost exclusively by Jesuit missionaries. Not only did they represent by far the largest portion of missionaries in China throughout the time of their mission, their numbers ranging from four in 1590 to eighty-two in 1701,[13] with their education as well as their modes of defending, consolidating and propagating their faith, they were very well prepared to spread scientific knowledge.

Shortly after the formation of the order in the first half of the sixteenth century, the Jesuits had become the intellectual bridgehead of the Catholic Church in its struggle against Protestantism and a major tool for its own spiritual renovation. The Jesuits propagated an integrated Christian worldview in which natural philosophy was of outstanding importance as an ancillary science of theology. To disseminate knowledge and faith and to educate the next generation, they established a growing network of schools and colleges which stretched across Europe (Krayer 1991, 7). The pursuit of the mathematical sciences, which consisted of the *quadrivium* arithmetics, geometry, music and astronomy, and included practical sciences such as optics, geography and mechanics, became the speciality of the Jesuit order, even though its place in natural philosophy remained controversial within the Church and even within the order itself. While the proponents of a thorough mathematical education had only limited success in shaping the colleges' curricula (Krayer 1991, 24–42), they were able to establish a Jesuit tradition of science education through informal seminars and specialized academies. Most prominently, Christopher Clavius (1538–1612), mathematician, astronomer and leading contributor to the prestigious project of Gregorian calendar reform, established a school of mathematics at the Collegio Romano, the Jesuits' elite institution in Rome. Among the first Jesuits to obtain permission to settle on

[12] On Islamic astronomy in China during the Yuan and Ming dynasties, see (Yabuuti 1997); on instruments of Islamic origin, see in particular 14–17 and the discussion in (Dold-Samplonius et al. 2002, 340–342).

[13] For a statistic of missionaries in China from 1590 to 1815 according to their order or congregation, see (Standeart 2001, 307–8).

the Chinese mainland from 1583 on, several were trained at the Collegio Romano, most prominently Matteo Ricci (1552–1610), a pupil of Clavius.

While the Jesuits were thus well-equipped to spread scientific knowledge, their actual strategic use of science in China, which brought about the transmission of scientific knowledge, can only be understood as a reaction to Chinese culture.[14] In fact, nowhere in the world did the Jesuits make such systematic use of science to support their mission as they did in China where they were confronted with a highly developed, self-contained and stable cultural system—a nut they were ultimately unable to crack. Two aspects of the strategy for Christianization adopted by the Jesuits in this environment were crucial for the upcoming transfer of scientific knowledge: top-down evangelization and accommodation to Chinese culture.

Top-down evangelization. The Jesuits tried to convert members of the ruling class, ideally the emperor himself, in the hope that the subjects would then follow his example. While this strategy may have been inspired by European and, in fact, Japanese precedents (Gernet 1985, 16), it also paralleled the hierarchical structure of Chinese society. The ruling class of imperial China was at the same time its intellectual elite, a fact ensured for centuries by a tough examination system for selecting prospective bureaucrats. The Jesuits' main targets for conversion were thus highly educated scholar-officials.

Accommodation to Chinese culture. Apart from India, China was the only country in which the missionaries tried to adapt completely to the indigenous culture. The Jesuits learned the Chinese language and writing system and adopted the lifestyle of Chinese scholars. In the first years of the mission, Ricci had adapted to a Buddhist lifestyle but soon must have realized that in this way Christianity could at best achieve a position on a par with Buddhism and Taoism, which, from the viewpoint of orthodox Confucianism, would always remain potentially heterodox. In order to become the dominant faith, Christianity had to take on Confucianism.

The missionary effort in China thus led to the encounter of two intellectual elites, each representing a culture with a highly elaborate knowledge system and advanced technology. It was against this background that the wide-spread habit of colonialists and missionaries to impress indigenous peoples with all kinds of gadgets developed into a systematic use of scientific knowledge to attract the learned Chinese's attention and convince them of the high level of European civilization. In this development, corresponding traits between the two cultures further enhanced the transmission of knowledge, which, in the course of the mission, took place in three contexts: 1) personal contacts between Jesuits and Chinese scholars; 2) expert services rendered by Jesuits on commission of the Chinese state; 3) Jesuits' private tutoring of the Chinese emperor. In all three contexts, the Chinese

[14] For a concise description of the Jesuit strategy as a reaction to Chinese culture, see (Standeart 1999); for a comprehensive account of the Christian missions in China from late Ming to mid-Qing times, see (Standeart 2001, 113–906).

side did not act as passive receiver, but rather prompted or requested the transfer of knowledge against the background of an agenda of its own.[15]

Figure 11.1: The Jesuits Matteo Ricci, Adam Schall von Bell and Ferdinand Verbiest. From Johann Baptista du Halde, *Ausführliche Beschreibung des Chinesischen Reiches und der grossen Tartarey*, Rostock 1749, p. 93. Permission of the Max Planck Institute for the History of Science Library.

1. *Personal contacts between Jesuits and Chinese scholars.* In the early decades of the seventeenth century, Jesuits like Matteo Ricci, Sabatino de Ursis (1575–1620) and Giulio Aleni (1582–1649) succeeded in converting a few Chinese scholars—most prominently Xu Guangqi 徐光啟 (1562–1633), who later became Vice Minister in the Ministry of Rites and was the highest-ranking convert the Jesuit mission would produce[16]—and worked with them on rendering European knowledge in Chinese writing. Through the presentation of European technical and scientific achievements, the Jesuits hoped to arouse the interest in their teachings of a broader group of scholar-officials, and eventually also of the imperial court.[17] The Jesuits' expertise in mathematical and practical matters paralleled a growing concern for such matters among Confucian scholars toward the end of the Ming 明 dynasty (1368–1644). Serving a state that was becoming increasingly dysfunctional, they

[15] For an overview of the role of the different branches of the sciences in the Jesuit missionary effort, see (Standeart 2001, 689–808).

[16] On different aspects of Xu Guangqi's life and work, see (Jami et al. 2001).

[17] Ricci's strategic use of science may have been modeled partly on the experience he had made with his famous world map of 1584, which had generated wide interest among Chinese scholars and provided him with many important acquaintances; see, for example, (Gernet 1985, 20–21).

more than once interpreted the neo-Confucian term *shixue* 實學, which may be translated as 'solid studies,' in the sense of practical studies which they pursued with the aim of improving statecraft. Together with the Jesuits, but also on their own, they published books on surveying, geography, water control, military technology, mechanical devices and astronomy. But also works of 'pure' mathematics were praised as a necessary basis for mastering practical affairs, as is exemplified in Xu's preface to the *Jihe yuanben* 幾何原本 (1607), the Chinese translation of the first six books of Euclid's *Elements* which he had prepared together with Ricci (see Figure 11.2). After the dynastic change in 1644, such close private co-operation between Jesuits and Chinese scholars became the exception, while the Jesuits became more successful in working for the imperial court.[18]

2. *Expert services on commission of the state.* The converted Chinese associates of the Jesuits not only urged their foreign friends to publish on scientific and technical matters, but also sought to have them apply their expertise directly for the good of the dynasty. The missionaries, on the other hand, by offering their services could hope to make themselves indispensable in China and to come closer to courtly circles. The three main fields in which Jesuit expertise matched Chinese demands were astronomy, military technology and geography.

   Astronomy. The need to revise the imperial calendar had been perceived by Chinese officials since the end of the sixteenth century. The imperial calendar was of crucial importance for the state. It was officially issued by the emperor and every dynasty (and sometimes single emperors) issued a new one at the beginning of their reign. The fate of an emperor or dynasty could depend upon the reliability of the calendar: mismatches between predicted and occurring phenomena were interpreted as bad omens and could incite rebellion against the ruling family. Ricci had understood the importance of scientific expertise, especially in astronomy, for the Jesuit mission and at an early stage had called on his European home base to send more missionaries trained in the sciences. These were Johann Adam Schall von Bell (1592–1666), Johann Schreck (latinized Terrentius, 1576–1630) and Giacomo Rho (1593–1638), who arrived together with Nicolas Trigault (1577–1628) when he returned to China in 1618. In 1629, without being given office, they began to revise the calendar under the supervision of Xu Guangqi at the newly founded Calendar Office (*Liju* 曆局), where they had more than twenty Chinese collaborators. After the dynastic change from Ming to Qing 清 (1644– 1911), the Jesuits were given office, even that of the head of the

[18] A major cause for the retrogression of the Jesuits' missionary success among the Chinese elite can be found in the change of intellectual climate in seventeenth-century China, from the perception of crisis and exceptional openness to foreign ideas in the first decades of the century to the concentration on the domestic classical traditions under a foreign but stable rule at its closure; this development is sketched in (Wills 1994).


36 EVCLID. GEOM.

PROBLEMA I.
PROPOSITIO I.

SVPER data recta linea terminata triangulum æquilaterum constituere.

IN omni problemate duo potissimùm sunt consideranda, constructio illius, quod proponitur, & demonstratio, quâ ostenditur, constructionem rectè esse institutam. Vt quoniam primum hoc problema iubet constituere triangulum æquilaterum super data recta linea terminata quacunque, ita vt linea recta proposita sit vnum latus trianguli. (Tunc enim figura dicitur constitui super recta linea, quando ipsa linea efficitur vnum figuræ latus) idcirco primum oportet construere ex principiis concessis triangulum aliquod, deinde demonstrare, ipsum eâ ratione constructum, esse æquilaterum, hoc est, habere omnia tria latera inter se æqualia. Quod idem in alijs problematibus perspici potest. Hæc etiam duo reperiuntur ferè in omni Theoremate. Sæpenumerò enim vt demonstretur id, quod proponitur, construendum est, atque efficiendum prius aliquid, ceu manifestum erit in sequentibus. Pauca veró admodum sunt theoremata, quæ nullam requirant constructionem.

Sit igitur proposita recta linea terminata AB, super quam constituere iubemur triangulum æquilaterum. Centro A, & interuallo rectæ AB, *a* describatur circulus CBD: Item centro B, & interuallo eiusdem rectæ BA, alius circulus describatur CAD, secans priorem in punctis C, & D. Ex quorum vtrouis, nempe ex C, *b* ducantur duæ rectæ lineæ CA, CB, ad puncta A, & B; Eritque super rectam AB, constitutum triangulum ABC, hoc est, figura rectilinea contenta tribus rectis lineis. Dico, hoc triangulum ita constructum necessariò esse æquilaterum. Quoniam rectæ AB, AC, ducuntur ex centro A, ad circumferentiam circuli CBD, *c* erit recta AC, rectæ AB, æqualis: Rursus quia rectæ BC, BA, ducuntur ex centro B, ad circumferentiam circuli CAD, erit recta BC, rectæ BA æqualis. Tam igitur AC, quàm BC, æqualis est rectæ AB. *d* Quare & AC, BC, inter se æquales erunt, atque idcirco triangulum ABC, erit æquilaterum. Super data ergo recta linea terminata, &c. Quod faciendum erat.

a 3. *pet.*
b 1. *pet.*
c 15. *def.*
d 1. *pron.*

SCHOLIVM.

VT autem videas, plures demonstrationes in vna propositione conti-

古今算學叢書

賜同進士出身記名總理各國事務衙門章京內閣中書舍人加三級臣劉鐸編校

幾何原本第一卷　本篇論三角形　計四十八題

泰西利瑪竇口譯

吳淞徐光啓筆受

第一題

于有界直線上求立平邊三角形

法曰甲乙直線上求立平邊三角形先以甲爲心乙爲界作丙乙丁圜次以乙爲心甲爲界作丙甲丁圜兩圜相交于丙于丁末自甲至丙丙至乙各作直線即甲乙丙爲平邊三角形

論曰以甲爲心至圜之界其甲乙線與甲丙甲丁線等以乙爲心則乙甲線與乙丙乙丁線亦等何者凡爲圜自心至界各線

象數第二

幾何原本　卷一

象數第三

Figure 11.2: First proposition of the first book of Euclid in Christopher Clavius' influential edition (1607; first published in 1574) and the Chinese adaption and translation by the Jesuit Matteo Ricci and his Chinese collaborator Xu Guangqi (1865; first published in 1607). Permission of the Max Planck Institute for the History of Science Library.

Astronomical Bureau (*Qintianjian* 欽天監) which was first held by Schall, and, after a five year intermission, by Ferdinand Verbiest (1623–1688). It only ceased to be in European hands in 1826.[19]

Military technology. The late-Ming-dynasty state had a urgent need to improve its military technology since it was threatened from the inside by peasant rebellions and from the outside by Manchu attacks. Cannons based on European models had been cast by the Chinese since 1519, but the

[19]The long-lasting European directorship of the Astronomical Bureau did not bring about a continuing transfer of European scientific knowledge to China. As the Europeans' role in the Astronomical Bureau became increasingly institutionalized, one can discern a "progressive bureaucratic insulation of Western computational techniques as a routinized and circumscribed function of the Astronomical Bureau" (Porter 1980, 71), which increasingly distanced the Europeans' intellectual activities from the propagation of new developments within European science.

seventeenth-century Portuguese specimens, whose import from Macao together with Portuguese gunmen was instigated by Xu Guangqi and Li Zhizao 李之藻 (1565–1630), turned out to be superior. In the last years of the dynasty, Schall cast at least twenty pieces of artillery in commission of the state. After the dynastic change, Verbiest cast nearly 500 cannons which were used in the conquest of Hunan 湖南 and Taiwan 臺灣 and in putting down the rebellions that beset the young Qing dynasty.

Geography. As Ricci had done before him, Verbiest in 1678 called on his order to send more personnel competent in mathematics and astronomy to join the mission in China. This was answered by the deployment of appointed correspondents of the Académie Royale des Sciences through Louis XIV (r. 1643–1715), "the King's mathematicians," who arrived in China in 1685. Besides their work in astronomy and mathematics in the narrower sense, they were able make use of another practical science in which the Jesuits excelled: they became involved in a great surveying project. The rapid expansion of the Qing empire (and not least the fear of rebellion) made an accurate geographical representation of its territories a matter of state interest. The Kangxi 康熙 emperor (r. 1662–1722) commissioned a survey of the entire Chinese empire, which was supervised by French Jesuits and undertaken from 1708 to 1717. The emperor's interest in mapping the empire coincided with the Jesuits' interest in mapping the countries they were attempting to Christianize. Later in the eighteenth century during the Qianlong 乾隆 reign (1736–1795) Jesuits were commissioned with further surveying projects.

3. *Tutoring the emperor.* The Jesuits had long attempted to capture the attention of the imperial court, but it seems they were not granted an audience during the Ming dynasty (Standeart 2001, 492–495). It was only after the dynastic change in 1644 that the Jesuits were finally able to establish closer relations to the court and to the emperor himself. Thus, Schall became the tutor of the Shunzhi 順治 emperor (r. 1644–1661) who was only twelve years old in 1651 when he began to rule by himself. Later, the Kangxi emperor, who was highly interested in mathematics and astronomy but also in various other aspects of European culture, was tutored by Verbiest and by some French Jesuits.

All three contexts of knowledge transmission yielded books in Chinese on European science and technology (and the context of tutoring the emperor even a few in Manchu); in the course of the seventeenth century the Jesuits and their supporters published nearly 600 books, an estimated several dozen of them on European science and technology.[20] All three contexts yielded the manufacturing of European-style scientific instruments, most prominently Verbiest's large astronomical instruments which he produced for the Beijing observatory (including an

[20]For statistics and references to bibliographies of the Jesuit's scientific writings in China, see (Peterson 1973, 296; in particular note 5; Standeart 2001, in particular 600 and 631).

ecliptic armillary sphere and a celestial globe), but also telescopes. And all three contexts involved the direct teaching of certain topics of European science to the Chinese, whether individual late-Ming scholars who actively sought out the Jesuits, prospective Chinese co-workers in the courtly institutions, or a Qing emperor.

11.4 Constraints of the Jesuit Context of Knowledge Transmission

In order to fulfill their mission the Jesuits had to reconcile two incompatible political-religious schemes, i.e., schemes with different dividing lines between politics and religion. In the European scheme religion had far-reaching implications on moral and political life, but at the same time was counteracted by the secular powers of monarchy. In the Chinese scheme the moral and the political were domains of state orthodoxy (or 'state-religion') with no great counteracting power, while the various religions and sects were tolerated as long as they did not interfere with the state monopoly in political and moral affairs. Thus, from the perspective of the Chinese state, the Jesuits might have been allowed to propagate their religion for the sole purpose of self-cultivation, on a par with Buddhism, Taoism and popular religion. From the perspective of the Roman Church, on the other hand, such subordination to a non-Christian moral system, which prescribed ritual actions for ancestor worship and the cult of Confucius, could not be accepted.

This incompatibility explains the precarious situation of the Jesuits during the entire period of their mission. Matteo Ricci established a delicate compromise by declaring crucial components of Confucianism to be compatible with the Christian faith and by tolerating the performance of Confucian rituals by Chinese Christian converts. The careful search for compromise was continued by most later Jesuits, but it was constantly endangered by attacks from two sides: missionaries of orders other than the Jesuit and eventually the Church in Rome who feared the corrosion of the Christian faith through the Jesuits' concessions; and Chinese scholars and officials and eventually the imperial court who perceived the missionaries as intruding into the sphere of the state.

The conflict repeatedly hampered the transmission of science and eventually brought it to an almost complete halt. Thus, in the so-called "Nanjing incident" of 1616, the central government's first action against the missionaries, the Vice-Minister and acting Minister of Rites, supported by other officials, accused the missionaries in the two administrative centers of the empire, the northern and southern capitals Beijing 北京 and Nanjing 南京, of violating Confucianism and put them on trial. The four missionaries active in the two capitals were expelled to Macao and the remaining eight retired from the public scene. (At that time, a total of twelve missionaries, all Jesuits, were working in China.) In consequence of this incident, from 1616 to 1622 all publication activities of the Jesuits, including those on science, were halted (Hummel 1943, 453; Peterson 1973, 296).

From the mid-seventeenth century, the Roman Church intervened through papal decrees in the controversy that took place between the different orders operating in China about the proper attitude toward the Chinese rites (and also about how to render central Christian concepts such as 'God' in Chinese).[21] In 1704 the pope condemned Chinese rites such as sacrifices to ancestors or to Confucius (and forbade the use of much of the Chinese Christian terminology Ricci had introduced). In 1706 the Kangxi emperor issued the order that all missionaries would have to follow 'the rules of Matteo Ricci' or leave the country. After the reiteration in 1715 of the papal decree condemning Chinese rites and the intervention of papal legates in China, who in the eyes of the Kangxi emperor were interfering in China's internal affairs, the emperor finally condemned the Christian activities, declaring that their religion

> […] actually does not differ from the heterodox and inferior talk of Buddhists and Taoists; it is the acme of unlawful nonsense. Henceforth Westerners must not be allowed to practice their religion in China. We may as well prohibit it, so as to avoid a lot of trouble.[22]

The prohibition of Christianity was enacted by the Yongzheng 雍正 emperor (r. 1723–1735) in 1724. While Christianity lingered on in the provinces and Jesuits continued their work as foreign experts at court, this decision deprived the missionaries of the perspective to win the Chinese elite and the emperor over to Christianity and thus destroyed what had been the conditions for the emergence of the transmission of European scientific knowledge to China. This may be taken as marking the end of any vivid form of such transmission in the early modern period.

But the transmission of science was not just the victim of a political-religious struggle. Chinese opposition to the introduction of European science in fact played a major role in the attacks on the Jesuits. This is especially the case for their activities in astronomy owing to the close relation of calendrical science with state orthodoxy. There is evidence that it was the attempt of the Jesuits and their Chinese convert associates to promote a calendar reform based on European astronomy that alarmed the officials into taking action against the Jesuits, thus initiating the Nanjing incident. And a central accusation leveled against the Jesuits was their alleged dismissal of the basic Confucian relationships like that between sovereign and minister through their astronomical theories. In Chinese traditional representations, the relationships between the sovereign, his wife, his administrators and the common people were correlated with those between the heavenly bodies, while Aristotelian cosmology separated them by dividing the heaven into several orbs.[23]

[21] On the 'rites controversy,' see, for example, (Standeart 2001, 680–688).

[22] Imperial autograph comment, cited after (Standeart 2001, 498).

[23] Several heavens *tian* 天, as the spheres were rendered in Chinese; (Gernet 1985, 61; Standeart 2001, 510).

The Jesuits' heading of the Astronomical Bureau set their science directly in the context of Chinese state orthodoxy. Their performance was judged not only by the precision of their predictions, but also by how they integrated traditional elements of Chinese calendar making in the context of their new methods of calculation, and how they performed other rituals that belonged to their duties such as the selection of auspicious times and places for imperial funerals. This made the Jesuits and their science particularly vulnerable to attacks by conservative officials. Thus, in the Calender Case of 1664, Schall was accused of selecting an inauspicious date and site for a burial. In April 1665 Schall and seven officials of the Astronomical Bureau were sentenced to death. Schall was later pardoned while five Chinese Christian officials were executed.[24]

11.5 The Impact of European Scientific Knowledge on the Chinese Tradition

Despite the fact that the transmission of scientific knowledge was not the primary concern of the missionaries, they were, in a way, more successful in transmitting science than in transmitting their faith. At least among the learned Chinese, their science aroused much more interest and reception than did their religion. But also European science was not received as a whole. Outside the small circle of their convert associates, the view was widely held that the Europeans were good at calculations but bad at 'fathoming the principles' (*qiongli* 窮理). Thus, what was presented by the Jesuits as integral parts of one worldview (mathematics, Aristotelian philosophy and Christianity) was dissected and the parts were received with very different intensity. European knowledge was largely perceived as complementing the domestic traditions, as may be illustrated by a statement of Zhou Ziyu 周子愚, the Vice Director of the Astronomical Bureau in the mid-1610s, who wanted European scientific works to be translated and be "taken to supplement the [Chinese] basic canons."[25] Accordingly, the transmission was most effective in the domains of mathematics and mathematical astronomy.

Mathematics. Western methods of written calculation were introduced and in learned circles replaced the use of the abacus, which had earlier replaced traditional Chinese rod calculation. Trigonometric and logarithmic tables, as well as new instruments such as Napier's bones and Galileo's proportional dividers came into use. Hybrid works, merging Chinese and European mathematical traditions were compiled, such as *Shuli jingyun* 數理精蘊 [*Collected Basic Principles of Mathematics*] which was first published in 1723 at the newly created imperial Academy of Mathematics (*Suanxue guan* 算學館) and served as a textbook. It was realized exclusively by Chinese mathematicians, but integrated revised lecture manuscripts written by the Jesuits when tutoring the emperor. In this book, European and Chinese methods for solving the same mathematical problems are presented side

[24] On the 1664 Calender Case, see (Chu 1997).
[25] Cited after (Engelfriet 1998, 331).

by side and, besides the traditional Chinese scheme of problem and method of solution, definitions, geometric constructions and other elements that reveal the influence of Euclid can be found (Jami 1994, 233).[26]

Astronomy. In the calendrical astronomy of the imperial court, Western methods of calculation were established, but without teaching the Chinese the astronomical and physical theories on which they were founded. Thus, in the eighteenth century star catalogs were updated by relying on European data and the ephemerides were calculated on the basis of Newtonian theory, which was not introduced to China before the second half of the nineteenth century. There was an increasing interest in astronomy outside the imperial court. Scholars discussed geometrical world systems like the Ptolemaic (geocentric) or the Tychonian (geocentric, but with planets revolving around the sun). They synthesized Chinese and European ideas on cosmology (Henderson 1986)[27] or integrated European knowledge on astronomy, like the existence of Jupiter's satellites, into a basically traditional Chinese framework, for example, in the work of Jie Xuan 揭暄 (1613–1695).[28]

While large portions of European scientific knowledge were thus integrated into the Chinese corpus, the Chinese image of scientific knowledge as well as its institutional and social embedding remained largely unaltered. Verbiest's bold attempt to introduce Aristotelian philosophy into the state examination scheme failed, as did the French Jesuits' plans to create in China an academy on a par with the French Académie Royale des Sciences. Instead Verbiest and the French Jesuits became servants of the Chinese institutions.[29]

Still, the massive influx of foreign knowledge seems to have appeared threatening enough to the Chinese to necessitate a justification for its use, in particular in the context of the imperial calendar. A widely employed strategy was the advocation of the theory of the "Chinese origin of Western science" (*Xixue zhongyuan* 西學中源). It implied that the Europeans were the heirs of an ancient Chinese math-

[26]Further works of Chinese mathematics which reveal an influence by Western mathematics are discussed in (Jami 1996).

[27]Examples are the syncretistic world systems of Mei Wending 梅文鼎 (1633–1721), who discussed the physical reality of the (possibly interpenetrating) spheres and the outermost immobile sphere as base of the prime mover, and of Wang Xishan 王錫闡 (1628–1682) who devised his own Tychonic system (Henderson 1986, 131–132).

[28]Chen Yue, personal communication. Nathan Sivin has argued that the Chinese scholars' negligence of the Copernican worldview was due to the fact that the Jesuits' early presentations of it were misleading, while the later correct presentation then contradicted their earlier statements (Sivin 1973, 103 and *passim*). From this perspective, the early failure to introduce Copernicanism to China appears to be a mere consequence of the constraints of the Jesuit context of knowledge transmission. In view of the fact that in Europe, too, a 'correct' presentation of Copernicanism was not readily available and that Copernicanism prevailed despite (and in a way even due to) the fact that it contradicted earlier ideas, it seems obvious, however, that more profound differences between the European and the Chinese knowledge systems at the time and their respective social embedding must be invoked to explain the different fates of Copernican cosmology in the two cultures. Cf. note 44.

[29]For the case of the French Jesuits, see (Jami 1994, 240).

ematical tradition which had allegedly spread throughout the world in the time of the Three Dynasties (roughly the first two millennia before the Common Era), but while surviving in the West it had been destroyed in China by the burning of books in the Qin dynasty (221–207 BCE) (Wong 1963, 38–39).

A major result of the introduction of Western scientific knowledge to China was a turn to the philology of Chinese science[30] which was, however, only one facet within a general trend to philology of early Qing scholars.[31] Chinese scholars searched for traces of an indigenous tradition in the sciences and were able to rediscover and reconstruct many classical writings of the Chinese tradition. The philology of Chinese mathematical texts became the main occupation of eighteenth-century Chinese mathematicians.

Summing up, in early modern times the Chinese were highly selective in their reception of Western science. They made use of mainly those aspects of Western knowledge that were useful for what they did anyway (calendar making, surveying,[32] calculating, and so forth). Branches of knowledge that were further removed from the Chinese traditions, like theoretical mechanics or syllogistic logic, did not make a lasting impact before the end of the nineteenth century. While the scientific knowledge the Jesuits brought with them enriched the body of Chinese theoretical knowledge, it hardly changed their image of knowledge and the way science was done in China.[33] The Jesuit introduction of science also did not result in an unbroken tradition of science exchange between Europe and China. In consequence, symbolic algebra and the calculus remained unknown in China before the second half of the nineteenth century. In view of the central role these new branches of mathematics played in the further development of European science in the eighteenth and nineteenth centuries, especially in physics, astronomy and mathematics proper, it becomes obvious that the ignorance on the part of the Chinese relates to the decoupling of Chinese science from almost all of the developments that characterize European modern science.[34]

[30]See, for example, (Sivin 1973, 72).

[31]See (Elman 1984, in particular 62–64 and 79–85).

[32]For example, in the *Celiang fayi* 測量法義 [*The Meaning of Methods of Measurement*] of 1608, which discusses "measurement and survey problems [...] in terms of Euclidean geometry; it also describe[s] the instruments used and their construction" (Jami 1996, 179).

[33]For the concept of images of knowledge, see Elkana (1981). See also chapters 1 and 9.

[34]This assessment stands in stark contrast to Joseph Needham's claim that around 1600 "there ceases to be any essential distinction between world science and specifically Chinese science," (Needham 1988, Vol. III, 437). In view of the differences that remained between the two science traditions as described here, and the difficult processes of the transmission of European scientific knowledge to China beginning in the second half of the nineteenth century, it is difficult to imagine what Needham's statement could mean. For a recent critical review of Needham's legacy, see (Schäfer 2010).

11.6 The Transformation of Knowledge in the Process of Transmission

When European science was transmitted to China, it was not just its immediate context changed, as the case of European astronomy in the service of the Chinese state exemplifies, but also the representation of scientific knowledge and indeed the content of science itself. This transformation was due mainly to the assimilation of this knowledge to Chinese knowledge traditions, an assimilation that becomes visible from the fact that European mathematical science and natural philosophy were presented as instances of *gewu qiongli* 格物窮理, a neo-Confucian term that may be translated as "the investigation of things and the fathoming of principles" which however had a distinct moral connotation.[35]

But the transformation already begins with the translation of European scientific writings into the Chinese language. There is, in fact, no evidence that Chinese scholars attempted to study the several thousand European books brought to China by the Jesuits in their original languages. The books on European science and technology written by the Jesuits and their Chinese collaborators were translations of European works, or collections of translations of passages from several European works, augmented with texts and passages specially prepared for the Chinese readers. The procedure of translation was mostly the one followed in earlier centuries in what may be called the greatest import of foreign knowledge into the Chinese culture before the introduction of Western science: the introduction of Buddhism. The translation was done in two steps: a Jesuit explained the original text in spoken Chinese (orally interpreted, *kouyi* 口譯) and a Chinese scholar wrote it down in literary Chinese (received or transmitted with the brush, *bishou* 筆受 or *bishu* 筆述). One may surmise however that the actual division of labor was not so clear-cut and that the translation of more difficult passages was preceded by discussions and a search for appropriate words.

We will not discuss here the preposterous thesis that the Chinese language, due to its structure or any peculiarity of its grammar such as the absence of inflection, was unsuited for the transmission of European science because, for instance, it was too ambiguous.[36] The actual problems for the translators were of lexical rather than grammatical nature. For most of the words that occurred in the European texts and that make up everyday language there were unproblematic Chinese counterparts. Clearly, the advanced state of Chinese technology facilitated the translation of texts on practical sciences like technical mechanics, water works or surveying. For the translation of the more theoretical terms, the translators had three options: they could either transliterate a term phonetically, thus treating the word like a place-holder that takes on meaning through explanation or usage; they could invent a new Chinese term that was composed of characters that disclose something about its meaning; or, finally, they could use a term from the

[35] See, for instance, (Henderson 1984, in particular 126 and 151).
[36] The claim of ambiguity is critically discussed, for instance, in (Wardy 2000, 6–10).

Chinese knowledge tradition that had a meaning somewhat similar to the term to be translated. The two latter options (which coincide in the case of monosyllabic terms) were by far the most prevalent.

This practice immediately raises the question of the degree to which the transferred knowledge was altered owing to the different connotations of the Chinese terms. Were there, for instance, connotations of the word *li* 力, which was often used to represent the Latin *vis* (force), that changed the meaning of statements in mechanics?[37] Did the use of the Chinese terms *shu* 數 and *du* 度 for number and magnitude, respectively, lead to misunderstandings about the separation of number and magnitude in the European tradition, since *du* originally means 'measure' and is closely associated with the practice of surveying?[38] These questions can only be answered by detailed studies of the usage and understanding of particular terms.[39] It is clear, however, that the impact of such connotations on the understanding of a new technical term is potentially greater the less the term's meaning is fixed within a network of other technical terms in the translated text, and the more the more the meaning of the source term is obtained from contexts external to the source text.[40]

There are in fact many cases in which the contexts given by the Chinese and European traditions were consciously merged, thereby producing concepts of double origin. Thus, while in their letters to Europe the Jesuits ridiculed the Chinese doctrine of the Five Processes as aberrant and absurd,[41] they integrated the Chinese idea that water conquers fire into their exposition of the natural place of the Aristotelian elements: fire strives to its natural place above; as soon as it is put under water, which is not its natural place, it is attacked by water and goes out. This merger was facilitated by the fact that in both traditions fire goes up while water goes down, a coincidence that may reflect shared basic human experiences of upward and downward motions. The argument is found in the *Yuanxi qiqi tushuo luzui* 遠西奇器圖説錄最 [*A Record of Selected Illustrations and Descriptions of Remarkable Machines from the Far West*] of 1627. It is repeated in Verbiest's *Qiongli xue* 窮理學 [*Cursus philosophicus*] which indicates that it was

[37] This question is tentatively discussed in (Damerow et al. 2006, 2–3). For a selection of passages from various ancient Chinese sources containing the term *li* 力, see (Zou 2006).
[38] See (Engelfriet 1998, 140).
[39] For discussions of representations of Western knowledge in Chinese terms focusing on the nineteenth and early twentieth centuries, cf. (Lackner et al. 2001).
[40] A furthergoing discussion of early modern translations of mechanical terms into Chinese is found in (Amelung 2001; Schemmel in press).
[41] Thus, relating the Chinese doctrine to the Aristotelian four elements, Ricci writes in a letter from 1595: "By adding metal and wood, and omitting air, they [i.e. the Chinese] count five elements (instead of four)—metal, wood, fire, water and earth. Still worse, they make out that these elements are engendered the one by the other [...]." Cited after (Needham 1988, Vol. III, 439).

made consciously rather than accidentally, possibly with strategic intent to blur the distinctions between the two knowledge traditions.[42]

The marginalization of deductive structure is another crucial transformation in the representation of knowledge that occurred in the early modern transfer of European scientific knowledge to China. The deductive organization of knowledge by means of definitions, postulates, axioms, theorems and proofs was a central aspect of science in the European tradition. Taking Euclid's *Elements* as its primary example, the tradition was followed well into modern times with a large part of the works of early modern science—including outstanding examples such as the Latin part of Galileo's *Discorsi* and Newton's *Principia*—more or less successfully copying this structure. The Chinese translation of the first six books of Euclid's *Elements* did indeed reproduce its deductive structure. However, the book, though praised by some Chinese scholars for its accurate style of argumentation, did not become a model in the Chinese tradition, not even in the case of geometry.[43] Other obvious occasions for the deductive presentation of scientific knowledge were not embraced. Thus, the first chapter of *Yuanxi qiqi tushuo luzui* contains a series of theorems taken from Simon Stevin's book *De beghinselen der weeghconst* of 1586, but presents them under omission of the proofs (Zhang et al. 2008, 92–119; Schemmel in press).

11.7 The Encounter of Two Systems of Knowledge

This discussion of the transmission of scientific knowledge from Europe to China in the early modern period has revealed a wide variety of factors—from epistemic to political—that influenced the consequences of the transmission. Despite their disparity they all originate in what may be described as the encounter of two systems of knowledge, each with its own distinct institutional and social embedding. As we have seen, what knowledge was actually transmitted and how this was transformed in the process of transmission was largely determined by the compatibilities and incompatibilities that existed between the two knowledge systems.

The transfer of European scientific knowledge to China was brought about by specific constellations of interests on both sides: the European (Jesuit) and the Chinese. The intellectual, political and religious conditions that made the knowledge transfer possible served, at the same time, as restrictions that hampered and occasionally even endangered its continuation. These conditions changed over

[42]The passage in the *Yuanxi qiqi tushuo luzui* reads: "For every body, if it is not at its [natural] place then this is necessarily contrary to [its] nature and other bodies can attack it. Therefore, to approach their respective natural place is what all bodies strive after. For example, fire naturally flames upwards. If you make it enter water then this is not [its] natural place and it will be extinguished immediately." (每物不在其所，則必與性相反，且別物得以攻之。故各就本所乃各物之所喜向也。假如火本炎上，使之入水，則非本所，便就滅息。) *Yuanxi qiqi tushuo luzui*, chapter one, section 23, see (Zhang et al. 2008, Vol. 2, 62). For the relevant quotation from the *Qiongli xue*, see (Yin 2006, 135).

[43]See, for example, (Martzloff 1980).

time during the Jesuit mission in China and by the mid-eighteenth century, the transfer of European scientific knowledge to China had come to a virtual halt.

The encounter resulted in a selective adoption of European scientific and practical knowledge and its assimilation to Chinese knowledge traditions, which to a large extent was shaped by the requirements of the Chinese imperial state. There were farther-reaching attempts at an integration of European scientific knowledge with Chinese traditions of natural philosophy and cosmology. These remained local endeavors, however, and did not bring about a new dynamics of knowledge production comparable to that in Europe.

The dynamics in the early modern European knowledge system came along with a high degree of instability. The science brought to China by the Jesuits was part of a knowledge system in transition and was itself in flux. It combined various partly incompatible knowledge traditions, such as Aristotelian philosophy, Archimedean mechanics and Euclidean mathematics, and had to integrate a growing body of practical knowledge originating from the technological developments of the time. The theoretical interpretations of the new practical experiences increasingly forced the emerging group of engineer-scientists into opposition to a worldview advocated by the Church that merged Aristotelian with biblical ideas. It was only through a reorganization of early modern society that the tensions inherent in early modern science and its cultural embedding could be eased.

The Chinese knowledge system at the time of the Jesuit intervention, by contrast, must be considered as highly stable. While a crisis was perceived toward the end of the Ming dynasty, the system recovered stability in the early Qing period. Notwithstanding the transformations of Chinese scholarship that took place during the seventeenth century, the internal structure of the knowledge system and its social and institutional embedding was at no point in the development subject to negotiation, as its quick adoption by the Manchu rulers conspicuously testifies.[44]

Thus in early modern times it was the unstable knowledge system of Europe that collided with the stable knowledge system of late traditional China. By the late nineteenth century the situation had completely reversed: the stable knowledge system of modern science with its solid embedding in an industrialized society

[44] At this point, it becomes particularly clear that the question of why the success of the transmission was so limited is closely related to Needham's classic question of why China did not develop modern science by itself (see, for example, (Needham 1969, 16); for critical reviews of Needham's question that appreciate its heuristic value, see (Graham 1971; Sivin 1982)). While any attempt to answer Needham's question lies outside the scope of the present chapter, it seems obvious that questions concerning the stability of the knowledge system are relevant, just as they are relevant to the problem of knowledge transmission from the West. Examples of such questions are: What practical knowledge was needed in centralistic China in comparison to Europe with its many competing political centers? How did new practical knowledge challenge traditional theoretical conceptions of the cosmos? And to what extent was there a power struggle between different strata of society in the context of which questions of natural philosophy and cosmology could have acquired a revolutionary potential? For the European case cf. (Lefèvre 1978, in particular 75–79). See also the discussion in chapter 9.

collided with the collapsing system of the Chinese elite whose inferiority had, in their own eyes, been proven by the military defeats at the hands of Japan and the West.

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Chapter 12
Normative Islam and Global Scientific Knowledge

Birgit Krawietz

The German poet and publicist Hans Magnus Enzensberger sensed that the massive intrusion of everyday technical products of Western civilization into North Africa and the Middle East must result in deep narcissist mortification that calls for compensation (if not revenge):

> Everything that daily life in the Maghreb and the Middle East depends on, every refrigerator, every telephone, every electric outlet, every screwdriver, not to mention high-tech products, presents itself to every capable Arab as silent humiliation. (Enzensberger 2006, 38, cf. 39–41; translation by the author)

However, a relatively low level of participation in the creative production of globally commoditized items is not unique to the Arabic Islamic world or the Islamic world as such (here always understood as a collective singular), but the same is true for most parts of Africa, Latin America and—until recently—also Asia. In addition, it is doubtful that Muslims outside or within Europe and the United States still perceive the wearing of trousers, the driving of cars, or the use of computers and the Internet, for instance, as typically Western. As a rule, Muslims do not pursue cultural difference by seriously considering avoiding or generally banning such amenities of modern life. Countries like the bulwark of the religious law of the Sharia, Saudi Arabia and the Arab states on the Persian Gulf, in particular, inundate their inhabitants with many more modern technical items than the average European civilian is accustomed to.

This does not mean, though, that I adhere to the thesis of Bassam Tibi. The German political scientist of Syrian background cruises the media and lectures on all continents that the Islamic world has emulated only a semi-modernity. In his perception, which is hailed by broad Western audiences, it is only in the fields of science and technology that the Islamic world opened up to a thorough modernization, whereas in the sphere of religion, culture and basic values, such as democracy, human rights and gender justice, it refuses influences and grimly adheres to its atavisms. Despite the media success of Tibi and those who have meanwhile followed suit (many of whom do not have any intimate knowledge of Islam as a religion or of Islamic societies), many Western scholars of Islamic Sciences reject such biased Western interpretations. Moreover, the potential conflict—and certainly not paradigmatic clash—between global scientific knowledge and normative Islamic knowledge runs deep *within* Islamically influenced societies themselves—and therefore likewise also among Muslims in “the West.” Both sets of knowledge and action—dogmatic and scientific—have been offered, adopted and appropriated throughout the Islamic world—including even social phenomena, such as the rise of Islamic fundamentalism since the 1970s.

Although fundamentalisms are often presented as a reaction to globalization, their actors in fact wholeheartedly employ the modern means of globalization and thereby become themselves effective globalizers. Against the thesis of a growing homogenization via cultural universals (such as reading, writing, hygienic standards and the like) as well as through the import of a globally available consumer culture, ethnologists, sociologists and the like have underlined the active and self-defining aspect of the rejection, adoption or selective use of certain goods and facilities. Denying a clear-cut total dichotomy between representations of normative Islam on the one hand and global scientific knowledge on the other does not mean that nowadays we cannot identify manifestations of normative Islamic thinking or distinguish them from secular knowledge. It has merely become even more difficult to decipher the broadened range of possible new shapes and combinations.

In the following, I will address the larger-than-life topic invoked in the title of this chapter in three major steps:

1. Part one starts with the development of different types of knowledge and deals with traditional institutions of higher Muslim learning (*madrasas*).
2. The focus then shifts to the democratization of access to secular knowledge through the introduction of Western achievements, such as modern educational systems and print media.
3. Finally, some structural problems that Western Islamic Sciences and other disciplines have in coping with normative Islam and its place in the modern world shall be identified.

The chapter provides a very rough overview spanning many centuries and has to cover a geographical zone ranging from North Africa in the West to Indonesia in the Southeast. No detailed attention can be paid to the different doctrinal outlooks of the majority Sunni Islam and the minority Shii Islam (10–15%).[1]

12.1 Knowledge Transmission and Institutions of Higher Learning

It goes without saying that Muslims do realize the difference between religio-normative and scientific knowledge. The Islamic tradition itself routinely distinguishes between so-called *ᶜulum naqliyya*, “transmitted sciences” and *ᶜulum ᶜaqliyya*, “rational sciences.” The former deal with knowledge transmitted primarily through revelation from “the God” (*allah*) via the angel Gabriel to the caravan

[1]Shii Muslims regard only the fourth Caliph, Ali, and his family as legitimate political and in the earlier period even spiritual successors to the Prophet Muhammad.

guide Muhammad in Mecca and later Medina (both in today's Saudi Arabia). The revelation process extended over a period of approximately twenty years. Sura five, Verse three of the Koran: "Today I perfected for you your religion" is assumed to be the concluding piece. The Prophet Muhammad died soon afterwards in 632 CE. In the oasis town of Medina he had been able to set up a small community based on Islamic guidelines. However, he did not manage to rally also the Jews and Christians of Medina or elsewhere to his cause. Muhammad regarded himself as the final messenger in a series of previous prophets including Moses and Jesus, who had been sent to other peoples with basically the same spiritual message. The second step of knowledge transmission was from the Prophet Muhammad to the growing community of his Arab followers. The latter preserved the "recitation" (*qur'an*) of God's speech in their minds and hearts (partly also in written form). In the middle of the seventh century CE, the third Caliph (political successor and symbolic leader of the Muslim community), ᶜUthman, organized a redaction of what became the official Koran corpus. This holy book is still an enigmatic piece of writing and the exact chronology and order of the various revelation parts is far from solved. However, to treat it like any other piece of writing (for a long time even to translate it) or to apply tools to it similar to those of historical Bible criticism is considered a threat that still causes serious repercussions.[2] Muslims regard the Koran as much "holier" than Christians consider the Bible because the book itself constitutes *the* central Islamic authenticating miracle—and not some magic deed of God's messenger. Islam is a religion of in*liber*ation, not one of divine incarnation. Since the Prophet Muhammad already practiced an ideal Muslim community, Islam is concerned with pious normative ortho*praxy*, less with orthodoxy. Therefore, experts in Sharia law, which theoretically comprises every aspect of the life of the individual and the society at large, have enjoyed a central role for ages.

For more than 1400 years, Muslims worldwide have been wrestling with this heritage. They have developed several disciplines dedicated to the interpretation of the sacred sources. So the Koran does not stand alone. There is also the Prophetic tradition (*Sunna*), that is, the words and deeds of the Prophet Muhammad as well as the Sunna of his followers in the early phase of Islam. Their pristine enactment of the Prophet's rulings, stemming from his interpretive Koran reading, ad hoc decisions, or subjective intellectual reasoning, is regarded as especially authoritative. Religious-normative argumentation regularly draws on examples and general guidelines taken from the first three generations of Muslims. In the early centuries of Islam, the transmission and development of such knowledge was not officially institutionalized. Pious circles in mosques or private homes provided the usual background for such activities. After the capital of the Islamic Empire had moved from Medina and Mecca, then Damascus (671–750), to its most impor-

[2] One of the last highly prominent scholars who had this bitter experience is the Egyptian Koran expert and scholar of Arabic literature and hermeneutics Nasr Hamid Abu Zayd, cf. (Abū-Zaid 2004). For important debates, see (Wild 1996).

tant location, Baghdad (762–1250),[3] Iraq provided a flourishing ground for the blossoming and differentiation of the *^{c}ulum naqliyya*, "transmitted sciences" that are also called "Koranic sciences." These finally comprised Arabic grammar (*al-nahw wal-sarf*), lexicographical writing (*^{c}ilm al-ma^{c}ani*), Koranic exegesis (*tafsir*) proper including further sub-disciplines such as the abrogation (*naskh*) of certain earlier verses by later ones, the historical circumstances of specific revelations (*asbab al-nuzul*) or hyperbolic speech (*majaz*) in the Koran, further artificial Koran recitation (*tajwid*), the science of tradition, that is, the Sunna as laid down in utterances of the specialists (*hadith*), Islamic jurisprudence (*fiqh*) and the principles of legal interpretation (*usul al-fiqh*), the fundamentals of religious dogma (*usul al-din*), the edifying life of the Prophet (*sira*), heresiography (*al-milal wal-nihal*) and the like.[4]

Given the vastness of the fast-growing Islamic Empire—the powerful conquest of the Iberian Peninsula in the West and initial intrusions into India started at the beginning of the eighth century—many foreign influences and local traditions in the conquered territories participated in the shaping of an—at no time unified—Islamic culture. A certain range of "secular" knowledge, such as geography, history, poetics, astronomy, mathematics and—to a lesser degree—logic has been accepted if not demanded to varying degrees, since such disciplines bore a vital importance also for religious studies. Mathematics, for instance, was deemed necessary to quantify legitimate inheritance shares and due shares of alms tax (*zakat*) on a person's movable property, as well as to pinpoint prayer times in different areas of the Empire. Other genres, such as lexicography, started as a religious discipline necessary for the interpretation of the Koran, but developed into independent research activities.

There are certain periods, regions and movements in history in which the Islamic world adopted foreign influences on an extraordinary scale and thereby tremendously transformed itself and others. The most famous example is the allegedly Golden Age in al-Andalus in Muslim Spain, which extended as far as Toledo. Its high—according to some, even utopian—quality is perceived in different dimensions. They range from peaceful interfaith coexistence and relationships, through translation activities (Arabic texts into Roman languages, Greek and Hebrew manuscripts into Arabic), agricultural advancements that the Arabs introduced to the Iberian Peninsula and progress in sciences such as modern medicine, to architectural cross-influences including libraries and places of learning. The time frame is a matter of ongoing debate, since some confine this idyll solely to the middle decades of the tenth century while others speak of several centuries. Different Muslim dynasties took part in the flourishing cultural activities of towns like Cordoba (the cultural center of the civilized world at the time), Granada and

[3] The caliphate was afterward reinstalled in Cairo and later transferred to Istanbul. The Turkish government abolished it in 1924.

[4] The best vivid accounts are (Berkey 1992; Chamberlain 1994; Lowry et al. 2004). On the manifold sub-disciplines, consult (Fischer and Gätje 1982).

Seville. In 1492, the Reconquista finally put an end to Islamic political rule in Western Europe. However, the scientific, philosophical and cultural activities of the Arabs and their transmission of ancient writings were decisive for the European rediscovery of Aristotle and thereby helped to launch the European Renaissance.[5]

Another fruitful cultural-scientific laboratory was at work in Iraq during the Abbasid reign. A blossoming Greek-Arab culture emanated from the "House of Wisdom" (*bayt al-hikma*), an important translation center, library and place of study in Baghdad. It assembled experts on manuscripts in Greek, Syriac and other languages from far afield, especially the Byzantine Empire. Strong emphasis was put on scientific writings from the ancient world, such as natural sciences, medicine and philosophy. Under the impact of the Mu^{c}tazila, a rationalistic theological school, three Abbasid caliphs in the first half of the ninth century including the famous Harun al-Rashid systematically fostered this institution.[6] Such an accumulation of knowledge also has to be related to the introduction of paper in the Islamic world, presumably by a Chinese prisoner of war in the middle of the eighth century. Paper was much cheaper and easier to handle than the previously preferred writing material papyri. Around the year 795, the first paper mill was erected in Baghdad. For a period of more than three centuries, mainly Hellenized Christians of the Middle East were engaged in significant translation and cultural transfer activities. The "rational sciences" (*^{c}ulum ^{c}aqliyya*) thereby flourished in the Islamic world for the first time.

Whereas the Renaissance hailed the Graeco-Arab heritage, Muslim scholarship often harbored reservations about philosophy (*falsafa*). Along with assumptions such as the original eternity of the world, logic is another bone of contention. Intellectual instruments that allow statements of what God must have meant by specific utterances or the indication that His message itself contains severe contradictions were regarded as suspicious or had to be reformulated in the sense that God's logic is of a higher order and often cannot be comprehended by the inferior human mind. Nevertheless, there have been many important philosophers in the Islamic world, like al-Kindi, al-Farabi, Ibn Sina (Avicenna) and Ibn Rushd (Averroës). However, philosophy was never officially accepted as the cornerstone of institutionalized higher Islamic learning, but in the end, even text-bound hardliners among the Muslim jurists, like the Hanbali school of law, opened up to the use of certain operations of logical thinking.

The institutionalization of religious knowledge in the sense of the transmitted Koranic sciences is intimately related to the influence of the Turkish dynasty of the Seljuks, which reigned in Iran, Iraq and Anatolia from the eleventh to the fourteenth century. Although they did not invent it, these Central Asian people and newcomer Muslims set up an official madrasa system that finally spread to many parts of the Islamic world. The *madrasa*, which means in Arabic "school"

[5] On the rediscovery of Aristotle in the twelfth century, see (Peters 1968).

[6] There are other phases of strong cultural mingling, such as the insertion and development of Persian culture in the ninth and tenth centuries, but this affects primarily the literary sphere.

(but has to be distinguished from basic Koran instruction in the so-called *kuttab*), is an institution of higher Islamic learning. Mostly financed by a pious endowment (*waqf*) from a local notable—at times even the emperor or a member of the ruling elite—it hosts students and provides an established setting (including dormitories) and a well-defined curriculum to acquire ^{c}*ilm*, religious knowledge, which guarantees an informed, pious way of life and a smooth pathway to paradise. Such instruction is therefore considered commendable. It is an irony of fate, though, that this Sunni restoration or Sunni revival (Hodgson 1974, vol. II, 45–49) as embodied in the successful trans-Islamic madrasa system was implemented by what were initially occupiers stemming from Central Asia.[7] Although there are many variations of the institutional and architectural profile of the madrasa, this institution came into existence from Morocco in the West to India in the East and far beyond.

Against the background of such multiple settings, there is no clear-cut dividing line between the religio-normative and the scientific realms of knowledge. The circumstances for inclusion or exclusion always shifted depending on the political framework, the dynastic, political and religious orientation of the relevant ruler or governing elite. Some sultans, that is, political rulers developed a considerable eagerness for certain sciences. Others had specific spiritual leanings, for example, toward Sufism, the Islamic mysticism that aspires to "hidden knowledge" (*ma*^{c}*rifa* or ^{c}*ilm al-batin*) for the initiated. It is less an intellectual discipline than a way of life and personal endeavor to build the inner spiritual self (and important social networks). Many scholars practiced Sufism on a personal level in interaction with a Sufi master, Sufi circles or adepts without necessarily offering relevant readings as intra-curricular activities of the madrasa. At times, a Sufi lodge, a Khanqah, was architecturally integrated into a madrasa; at other times, Sufism, like philosophy, was frowned upon or even persecuted.

Today, opinion differs on the madrasa as the epitome of traditional Islamic thinking. One could say that it recently advanced to become one of those ambivalent tropes of Orientalist perception that oscillate between fascination and revulsion. On the one hand, it offers architectural highlights of Oriental splendor, like the madrasas of Bukhara and Samarkand. On the other hand, the Taliban's seizure of Kabul in 1996 cast madrasas in a very bad light. Many Taliban (students) had spent years in Pakistan refugee camps near the Pakistan-Afghan border and picked up their fundamentalism in religious schools of that region. Madrasas in general therefore increasingly became perceived as a potential breeding ground for radical Islamism. They appear a relict symbolizing a backward-oriented type of education that preaches an obsolete radical Islam incompatible with the demands of modern life. For this reason, the Muslim systems of education and their underlying order of knowledge have once again become an important issue of Islamic Studies and many publications have followed suit.

[7] For a comparison of the madrasa with medieval European universities, see (Makdisi 1981).

Apart from the fact that madrasas have changed over time and especially since the nineteenth century, the main points of criticism are: the central role of memorization to the neglect of individual text interpretation, lack of reflection and critical thinking, a strong oral tradition, focus on authority and authoritative transmission of texts by passing a certificate (*ijaza*) from teacher to student and monastic control and discipline that leaves no room for individual recreation or personal scientific endeavors. Further criticism points to otherworldly, "medieval" content reflecting animosities toward the Crusaders, blindness to empirical rectification, habitual circular argumentation always bound to the imagined perfect community of the early Muslims as a role model, lack of trust in the future because utopia has already taken place, sycophancy toward possible funders and—to conclude this enumeration of complaints—education of only male students or complete gender-segregated schooling, thereby reinforcing male hegemony in Islamic culture. This is not the place to relativize such allegations.

Western lay observers often do not realize that a mosque (*masjid*) cannot be equated with a madrasa in the sense of a center of higher learning. Although a larger mosque for Friday prayer (*jami^c*) may comprise private or even official study circles, the full-fledged infrastructure of a madrasa complex must still be distinguished from this type of mosque. This is especially true for the poor conditions of Islamic learning in Europe or North America these days. In most cases, the mushrooming mosques in these countries must not be mistaken for important Muslim think tanks. Although some Western (diaspora) mosque centers have recently developed a broader range of services and facilities, the majority of them do not carry out original religio-normative research. Mosque centers are usually not the best place to inform oneself about creative Muslim norm production on newly debated issues. Instead, for more or less progressive normative suggestions, one should turn to institutions such as the Islamic University of Rotterdam, the new professorships for confession-tied Islamic Studies in Germany (e.g., Münster, Frankfurt, Osnabrück and Erlangen) or the Dublin-based European Council for Fatwa and Research.[8] It would be a mistake to assume that an open house in an ordinary Western mosque allows even a glimpse of the richness and refinement of normative Islam.[9]

[8] On the latter, see (Caeiro 2010).

[9] The Egyptian-American lawyer and Sharia expert Khaled Abou El Fadl never tires of pointing out in many of his publications the sharp contrast between differentiated high-quality scholarship of pre-modern times and the deplorable normative production of modern fundamentalists. Nowadays Muslim polemists and fundamentalists are unable to live up to the standards of the traditional heritage they claim to represent or revive.

12.2 Broader Access to Global Secular Knowledge Through Westernization

Madrasas today either partially opened up to a limited range of modern secular knowledge or were fused into the modern educational system.[10] The third and most frequent possibility was the introduction of totally new structures of learning (and earning money) that challenge the importance of the old-style madrasa. In the course of the nineteenth century and especially from its second half on, the traditional institutions and scholars (*ᶜulamaᵓ*) in the Middle East and North Africa lost their previous role. Islamic hegemony was gradually reduced and to a great degree replaced by new forms of organization and instruction. Such developments also occurred in South Asia, where the worldwide majority of Muslims live. The Dar al-ᶜUlum Madrasa in the North Indian town of Deoband, for example, was founded in 1866 on the model of a British college, that is, by emulating "the formal setting of curriculum, paid staff, a campus with teaching halls and hostels," a format that was innovative in its time (Reetz 2010, 5).

Several reforms were carried out in the Islamic world, also in the spheres of the military, various state institutions and the judiciary. Under the impact of European reform ideas, the regimes—and first of all the Ottomans—tried to shape their economies in accordance with European role models. Many regions of the Islamic world finally became part of the mainly British or French colonial system. The introduction of new health systems, armies based on European models, modern-style universities and the establishment of industrial production and new vehicles such as cars, steamships and trains, influenced attitudes toward worldly goods and rationales as well as esteem for technical and other skills and knowledge. Dramatic changes also took place in the field of Islamic law. On European initiatives, Islamic law was partly canonized (*taqnin*) for the first time in its history, like the Anglo-Muhammedan Law in British India or the Ottoman *Majalla*. In addition, complete legal codes of European origin were transplanted into the new state law of some Islamic countries. As a consequence, a new class of state employees was needed with a new educational background.

Primary-level education was structured in these new terms and modern schools replaced many *kuttabs*. In Cairo in 1872, the Dar al-ᶜUlum was founded to educate teachers in modern subjects (in 1940 integrated into Cairo University). Secular knowledge reached the Islamic world increasingly through translations into Arabic, Persian and the like. Families in the Middle East started to send their children abroad to pick up European languages and study at one of the centers of European learning.[11] English and French (partly also Latin and Greek) entered the new school and university curricula. New teaching materials became necessary.

[10] For several detailed accounts and case studies, see (Hefner and Zaman 2007).

[11] For the report of a Muslim religious scholar who accompanied the first student mission to France, see (Al-Tahtawi 1989).

Christian Church authorities in Syria and Lebanon introduced the printing press to the Arab world in the eighteenth century. In the nineteenth century, it extended beyond this sphere. Newly founded Christian schools in the Middle East transmitted Western scientific knowledge to their students—later also including Muslims. In 1876, graduates of the Syrian Protestant College in Beirut, the first modern university in the Middle East, founded the monthly newspaper *al-Muqtaṭaf*, "the Anthology," which was later edited in Cairo. For decades, this magazine created a new platform for popularizing natural and rational sciences. The *Muqtaṭaf* was not the only publication of this type. Others focused, for instance, on history writing or literature and literary critique. In 1828, Egypt published the first Arabic newspaper, its state gazette. Other newspapers and magazines followed, especially since the second half of the nineteenth century. Starting from Syria, Lebanon and Egypt, this new format of orientating knowledge shaped a new form of public realm through massive borrowings from the European press and other publications. Glaß not only underlines the importance of manifold essays to instruct broadening audiences, but also stresses the vivid interaction via letters to the editor, spurring immediate reactions among those who wished to become involved, as well as launching a series of debates on a national and even international level (Glaß 2004). The so-called cultural renaissance (*al-nahda*), which started in Egypt in the late nineteenth and early twentieth centuries and encompassed the Middle East, fundamentally renewed the conception of knowledge and used the Arabic language as its basic tool. It was effectuated by large-scale adoption and appropriation of Western science and culture. It also created a market and taste for hitherto unknown literary genres, such as novels, theater plays, short stories and autobiographies. In consequence, bookshops, great magazines, opera houses and theatres contributed to shaping urban life and creating a broader public sphere.

After the withdrawal of the colonial powers, in many countries of the "Third World," nationalism has been strongly associated with secular and liberal ideas (Hourani 1962). In the first half of the twentieth century and well until the 1960s, secularization seemed to be the coming thing, including the strong public presence of women who had given up veiling. Some regimes had their flirtations with Arab socialism, such as Egypt and Syria, Iraq, Algeria and South Yemen. However, all the great narratives of Western-style progress rapidly wore off. The key experience was the traumatic defeat of Arab Forces in the Six Day War against Israel. Bombastic rhetoric had lured the Arab masses to believe that they would be strong enough to defeat "the Zionist enemy." After this and some other illusions had proven completely unsubstantiated, Islam has become an increasingly important factor with its doctrinal and normative reservoir, which seems to offer solutions for all sorts of questions and gives the impression of guaranteeing "authenticity" (*asala*) in a frightening world of modernity (*hadatha*). While some secular Arab intellectuals, like Sadiq al-ᶜAzm, Muhammad Arkoun, Said al-ᶜAshmawi, Abdallah Laroui, Georges Tarabishi and Fuad Zakariyya, are highly critical of such authenticity discourses,[12] it would be a mistake to discard their strong social importance for the construction of identity. Eager Muslim propagandists even went one step further and declared the Islamization of worldwide knowledge including social sciences to be a working program (Abaza 1992, 2002).

The rise of Islamic fundamentalism in the 1970s should not be understood as a total watershed. Islam as a modern ideology for the masses was (re-)invented, for instance, when the movement of the Muslim brotherhood was founded in 1928. Like ardent secular nationalists, dedicated Muslims started to employ the new media. Religious reform magazines, above all, the famous "Lighthouse" (*al-Manar*), served as discussion forums for progressive Islamic ideas. Its editor, Muhammad Rashid Rida (1865–1935), followed the credo of his teacher Muhammad ᶜAbduh (afterwards also the Grand Mufti of Egypt and Rector of Egypt's most important university, the venerable Azhar) that there was no fundamental contradiction between belief and reason. Print media not only enabled people to make contact with globalized secular knowledge; access to their own Islamic heritage (*turath*) also became popularized (Hamzah 2008). For the first time in history, the classical works of normative Islam, including the Koran itself, were—at least physically—open to the semi- and uneducated. Increasingly, old inner-Islamic conflicts flared up because people in one region suddenly became aware of what others believed, criticized or practiced. Historically local strivings suddenly turned into a framework for staging doctrinal conflicts elsewhere. Publications for larger masses (and no longer only expensive manuscripts for the privileged few) supplanted the *hajj* (the annual pilgrimage to Mecca which every Muslim is supposed to undertake once in his lifetime) as the most important stage to foster a consciousness of belonging to one global community of believers (*umma*). Reform ideas were henceforth picked up in remote areas of the Islamic world. In various regions, Islamic normativity also provided a counter-strategy to—mainly Western—"cultural imperialism" (*ghazw thaqafi*).

Whereas classical Islamic normativity had mainly featured comprehensive manuals of Islamic law, modern normative publications shifted the interest to specific topics that need to be discussed at a certain length. The inner-Islamic system of counseling (*iftaʾ*) correlates with Christian catechistic structures of question and answer as well as with Jewish Responsa literature. The Fatwa system is an alert mechanism to respond to novel situations by providing pious advice on newly emerging problems. Modern topics such as blood transfusion, organ transplantation, reproductive health, modern insurance systems and the like can thereby be treated in a relevance-oriented manner (Krawietz 1991). Experts on Islamic law have always respected non-religious knowledge (increasingly also labeled *ᶜilm*) to a certain degree and advised their pious petitioners to consult a medical doctor on

[12] Tarabishi even polemically "denounces the entire *turath*-discourse as a regressive (*nukusi*) reaction to the traumatic shock (*sadma, radda*) caused by the confrontation of the omnipotent overfather 'West,' depicted with phallic symbols (*khanjar Israil*, with its air-force in 1967)." He claims that this "led to a neurotic flight towards collectives depicted with female, maternal images (such as *umma, jamahir*)" (Riexinger 2007, 65, fn. 9).

certain issues. Those scholars who concede knowledge lacuna and accept scientific advice are much better off than those who practiced, for instance "scientific Koran interpretation" (*tafsir ᶜilmi*), a trend that identified things like telephones, planes, electricity, or the detection of microbes as already announced by the Holy Book. Without being able to go into any details here concerning the multiple forms of fusing scientific and normative knowledge in modern publications and products, certain confines of accepting a scientific hegemony become evident. An expert on Sharia law transgresses boundaries when he declares, for example, that fasting is detrimental to an otherwise healthy Muslim athlete or when he doubts the legitimacy of capital punishment on the basis of sociological findings on its deterrent effect. Another phenomenon is the increasing importance of a so-called "moral economy," that is, normative Islam as a marketing strategy to attract certain segments of customers. An example of this would be a Halal certificate for correctly slaughtered meat.

12.3 Problems with Normative Islam in Western Islamic Sciences and Beyond

Under the impact of migration and globalization, normative Islam is no longer a regional phenomenon. Addressed to the whole of mankind, it nowadays pervades and stirs up many societies worldwide. Through various means and media—most recently through the Internet—a Muslim believer in any country of the world can derive his normative orientating knowledge and appropriate it for personal daily practices or conflict resolutions, or let new popular brokers of knowledge do it for him (Gräf 2010). No official exclusion or abolition of the Sharia on the state level in one country would be able to hinder such multiple normative appropriations, which usually do not interfere with modern state law. Besides, it is impossible to say how many of the approximately 1.5 billion Muslims worldwide adhere to the doctrine of the normative primacy of the Sharia and what the exact practical implications and conflicts of such an outlook are for the state system they live in. Western jurisprudence is concerned with Islamic law only insofar as the latter enters the respective state law in a limited number of fields (mostly regulations of international private law) (Rohe 2004). Under such demanding circumstances, one might wonder whether modern Islamic studies can still be addressed as mere area studies and to what degree its experts are sufficiently able to deal with the phenomena described in this chapter. To be able to analyze the ways Islamic legal norms are (re)invented, mixed with one another and combined with secular knowledge, one would first need to have not only philological expertise, area studies competence and intimate knowledge of globalization theories, but also an idea of the contents and contexts of pre-modern Koranic sciences. Experts in Islamic sciences also need the ability to distinguish fundamentally between norms and facts. It would be desirable for them to be familiar with hermeneutical and methodological questions of Islamic law (*fiqh*) in order to trace how Muslim jurisprudence constructs creative solutions for new problems (*ijtihad*). Such challenges are uncomfortable and these skills are hard to master altogether for scholars of Islamic sciences, who have so many other issues to deal with. To my mind, the following has to be conceded: Western Islamic sciences are much less able (and willing) to deal with the sphere of traditional normative Islam and its multiple transformations in modern times than lay observers would dare to suspect. As such, their label "scholars of *Islamic* studies" is often misleading (Ammann 2008).

What are the reasons for this relative deficit? First of all, Europe has a very strong philological tradition in Arabic that stood in the long-time service of extended Bible studies. A deeper analysis of the political, cultural, economic etc. background of the modern Islamic world started only just over a century ago. Normative issues did not enjoy any special interest in this regard. Channels that might have enabled a deeper understanding for orthopractical systems, namely Jewish community life and rabbinic studies, were damaged and finally uprooted in Germany during the Third Reich. After the atrocities of World War II, there was a heightened sense of the necessity of divine law and the fundamental ethical outlook it provides. Theology is definitely the central field for experts on Christianity, but the high estimation of and interest in Islamic theology that set in left too many questions open about its mighty twin, Islamic law. Theology was treated as the key Islamic discipline—in unreflected analogy to the Catholic and Protestant creed. And Christian religious representatives lost many years in their quest for adequate official counterparts to engage in interreligious dialogues. Needless to mention, the problem of representation of Islamic authorities is still unsolved (Krämer and Schmidtke 2006). Other scholars of Islamic studies were mainly concerned with history, political systems in the Islamic world, the emerging study of modern Arabic, Persian or Turkish literature and so on. The impression reigned for decades that such fields emerged and emancipated themselves as disciplines in their own right from their previous status as mere sub-fields. Hardly any of these scholars would have imagined that their sphere of expertise also had significant normative Islamic underpinnings and bore intimate relations with normative Islam. And many of them are still in denial.

The rise of fundamentalism changed the situation and, everywhere in the West, brought about a strong demand for (I hesitate to call it an interest in) the study of Islamic law. Since then, there has been a steady flow of books and articles whose merits cannot be denied. However, there are so many complex problems intertwined with issues of modern history, politics and the arts that cannot be adequately addressed without including references to normative Islam. Nevertheless, there have been very few efforts to integrate the study of Sharia law interpretations into overarching topics of cultural history. Some of the barriers are of a persistent psychological nature, other resistances have mainly institutional-structural causes. Let us first turn to the emotive subtexts. For many people, Islamic law seems to symbolize an archaic stage of existence, long since overcome by modern man. It took the West a very long time to get rid of the worst burdens of its religious-dogmatic heritage and it is seemingly unwilling to reopen Pandora's box once again by confronting living versions of a potentially dangerous sister heritage. As long as secularization theories and globalization scenarios assuming an overpowering trend of global homogenization could be still upheld, the illusion reigned that one never had to look back. However, accusations and punishments of apostasy, the killing of non-Muslims on charge of blasphemy (like the Dutch filmmaker Theo van Gogh), pseudo-Islamic video executions, circumcisions in European capitals, withdrawal from coeducational swimming instruction, some Muslim officials' refusal to shake hands with women, the phenomenon of "repentant" artists and so on, could no longer be overlooked with the superior indignation of the civilized and cultivated. Despite all such occurrences, the quest to explore the aspirations, range and peculiarities of normative Islam and its discursive functions for Muslims nowadays has been quite limited.

The perception of Islamic law is still confined within what is regarded as its plausible boundaries. Colonialism and Western scholarship have created some containerized versions of what Islamic law is allegedly about, namely Muslim family law and—in certain countries also—penal and public law. Such issues are often related to and made important by human rights interests. In addition, attention is paid to those residues that seem to prevent a peaceful coexistence with Muslims in the West, such as veiling or Islamic ritual slaughtering. What might be called a pragmatic approach in dealing with normative Islamic aspects could also be interpreted as an escapist attempt to ban such seemingly anarchic forces. Scholars of Islamic sciences often prefer to deliver courses of container-like knowledge on normative Islam. Other accepted avenues—in addition to family law—are on the one hand gender studies and on the other legal pluralism, including locally valid customary law, which is of special interest for cultural anthropologists and legal scholars. That is to say, a certain segment of common interdisciplinary interest has developed in relation to Islamic normativity. These are, currently, its most familiar presentation forms on the academic market. Such shapes are generated and strengthened by the new world of Bachelor and Master studies. Often, Islamic law is presented as an ongoing not-yet, falling short of the enlightenment of Western modernity. In this sense, some countries get better marks for their state law (*qanun*) system than others, because they seem to be already on the right path. In this sense, they are offered to Western audiences as "best practice" examples.

My plea, however, is that normative Islam should no longer be treated as either a confined element of state law, a mere set of ritual regulations and moral guidelines or some other separate small box comparable to a variety of quite confined genres of so-called Koranic sciences, such as Arabic grammatical writing or eschatology. On the contrary, normative Islam is in many cases comprehensive or, negatively speaking, totalitarian in its worldview. Its borders are increasingly fuzzy and often merge into a kind of current how-to manual. Only minor parts of it have been sanctioned as state law in some countries of the Islamic world. The majority of its regulations and discussions receive little Western scientific attention. This is all the more astonishing because Muslims instrumentalize many normative debates to stage certain ideological agendas. The depicted collective self-restrictions of Western scholarship examining Islamic normativity should be overcome. What scholars often try to ignore is the multiple entanglement of normative issues with (even modern) Islamic history and culture in general. Hardly any field of society is so modern or post-modern that it is exempt from normative issues. No wonder many aspects of Islamic cultural history and reform proposals have not yet been treated in decent monographs. In fact, voices of normative Islam are omnipresent, pervading many facets of life and infiltrating many literary genres even beyond the doctrinal Koranic sciences. An encompassing study would also need informed references to the history of knowledge or media theory.

A last factor detrimental to the academic exploration of Islam in the sense of Koranic sciences (theological and normative) is the recent development that normative Islam has been handed over from largely non-Muslim scholars of Islamic studies to the newly installed education of Muslim teachers in Germany (*Islamische Religionslehre* or *Islamische Studien*). To my mind, normative Islam or, to be more precise, the potentials of Islamic jurisprudence for the study of cultures, is too important to be left to this latter—and at any rate still small—group of people.

In sum, despite its official widespread abolition or only piecemeal adoption as state law, Islamic law and normativity are, in one way or the other, omnipresent. This is a time when state-generated systems are challenged by many non-state or translocal actors. The paradigm of the *Umma,* the community of the believers, offers a means for global messages. Islamic law is a battlefield, but not in the usual sense. It is a battlefield because there are so many different parties, interests and ideologies involved, so that it is highly important to trace their respective strategies of presenting, excluding, transforming or criticizing normative Islam. Neither secular Western jurists, nor ethnologists, human rights watchers, or representatives of gender studies will be motivated or able to draw enough attention to those multiple fields of Islamic normativity that are still insufficiently analyzed and lie outside the realm of their interest. Finally, there is no adequate overall terminology, much less typologies, to analyse the multiple patterns according to which pre-modern normative knowledge is today appropriated for global discourses on health, psychology, ecology, moral ethics and so forth.

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Chapter 13
From Khwarazm to Cordoba: The Propagation of Non-Religious Knowledge in the Islamic Empire

Gotthard Strohmaier

13.1 Introduction

The fact that so much Greek knowledge was transferred to Western Europe via the multi-faceted culture of the Islamic Middle Ages can be explained by various factors. The first was the tolerance of the victorious Muslims toward the *People of the Book*, among them Christian Syrian and Arab intellectuals, heirs of the ancient School of Alexandria who went on to teach more secular-minded spirits in Baghdad in the ninth century. Almost the whole syllabus of philosophy and the sciences still alive in late antiquity thus became accessible in good translations and superseded the Indian influences that were more prominent at the beginning of the Abbasid era. Another factor was the eradication of pagan traditions outside the realm of Christian influence, which created a homogeneous cultural area, dominated not only by the Koran and Muslim orthodoxy, but also—especially at the courts—by Aristotelian philosophy and Ptolemaic astronomy. As later in the European enlightenment Socrates became an iconic figure. At the Western margins of this area, where the Muslims had to retreat before an increasing Christian power, Latin Scholasticism acquired treasures of Arabic manuscripts that were translated in due course.

13.2 A Special Position of the Christians

Khwarazm, an oasis on the Amu Darya River delta and the site of an ancient culture, was ravaged by various catastrophes over the course of its history. One of these was the Arab conquest in the year 712. The universal scholar al-Bīrūnī (973–1048), a native of this land, described this event in his *Chronology* with the following words:

> After Quṭayba ibn Muslim al-Bāhilī[1] had killed their learned men and priests and had burned their books and writings, they became illiterate and had to rely on memory for the knowledge they required. (al-Bīrūnī and Sachau 1923, 48, 12–14)

[1] An Arab military leader by order of al-Ḥajjāj ibn Yūsuf, governor of the Umayyads in Iraq, see (Bosworth 1982, 541–542).

C. E. Bosworth believes this succinct declaration to be exaggerated (Bosworth 1978a, 1062). But even a scholar as interested as al-Bīrūnī in the history of his homeland could not relate more than fragmentary and imprecise accounts about the time before the Islamic conquest, as can be shown today by numismatic research (Vaynberg 1977, 80–84). This testifies to the fact that the region suffered from a cultural vacuum that became filled over the course of time with Islamic religion and also with knowledge of non-Islamic origin contained in Arabic literature, foremost of Greek origin.

The victorious Muslims had treated the Christians in Egypt, Syria, North Africa and Spain more indulgently. According to the Koran, these populations were not heathens doomed for the sword, but *People of the Book,* i.e. of a divine revelation prior to the Koran. As such, their educational institutions also remained intact: the School of Alexandria and the Syrian theological academies and hospitals, which were also sites of medical training. In the Abbasid capital of Baghdad, Syrian and Christian Arab intellectuals impressed their keen Muslim pupils with their superior knowledge of Aristotelian philosophy, of Ptolemaic astronomy and of Galenic medicine.

Al-Bīrūnī reports a conflict that had erupted in Baghdad one hundred years previously between the Nestorian Christian philosopher Abū Bishr Mattā ibn Yūnus and the Mu^{c}tazili theologian al-Jubbā$^{\supset}$ī. The latter, in this respect still beholden to the worldview of the Koran, did not believe that the Earth is shaped like a sphere and acknowledged before an assembly of scholars, known as a *majlis*, that he had indignantly ripped out pages on this subject from a tract by Aristotle, at which point the philosopher ridiculed him before the entire assembly (al-Bīrūnī and Bulgakov 1962, 158–186). It is understandable that the audience would have been interested in consulting the tracts of Aristotle themselves. Arabic translations of a plenitude of Greek texts were commissioned and well paid. They were copied over and again and so propagated over the entire vast territory of Islam, from Cordoba in the West to Khwarazm in the East. There was some resistance, like that of Marcus Porcius Cato *the Elder* (234–149 BCE) of Rome who, in a previous age, had battled against what he believed to be the pernicious influence of the Greeks.[2] But in both instances the educated class prevailed in appropriating anything that might be of value, rather than simply leaving it in the possession of the subjugated people.

13.3 A New Kind of Uniformity

As in the ages of Hellenism and the Roman Empire, a growing uniformity in the worldly sciences and philosophy took place across a vast territory, expedited by scholarly journeys and trade in books, now produced with the inexpensive paper adopted from the Chinese. We can detect the same uniformity in other areas as well, even in those that were cultivated alongside religion and without any internal

[2] Cf. (Nutton 1986).

connection to it, such as music and musical instruments, and decorative patterns in handicrafts. One must not neglect the strong cultural ties that united all Muslim peoples, as was done in the first volume of a seven-volume history of philosophy published in Moscow in 1957, where the thinkers of the East, too, were duly acknowledged, but in questionable order. After the Chinese, Indians and Japanese came the Iranians and the Arab peoples with an appendix of Jewish philosophers, and at the end the peoples of Central Asia and Transcaucasia, separated from their Muslim brethren by Byzantines in between. This was methodological nonsense, but it fit well with Soviet nationalities policy (Dynnik 1957).

When the young Ibn Sīnā (980 or earlier–1037) received permission to visit the court library of the Emir in Bukhara, he immediately requested access to the catalog of books by the "Ancients" (Gohlmann 1974, 36f.). The "Ancients" were none other than the ancient Greeks, above all Aristotle along with his disciples and commentators, and the physician Galen of Pergamon (129–216 CE), who was also revered as a philosopher in his own right. As apparent from the frequent mention of their names, these were the dominant figures in the scientific and philosophical discourse. This circumstance may not be interpreted to mean that this discourse was already dominated by "European" influences, as is still the case today. The Greeks who lived around the Mediterranean were not Europeans in the contemporary sense (Strohmaier 1998), and more than a few authors who wrote in Greek were not ethnic Greeks themselves. The perpetuation of Greek philosophy in the Islamic space, emanating primarily from the School of Alexandria, was not an imported phenomenon, but just as indigenous as Oriental Christianity. As such, I would not speak of a "first international epoch of science"[3]; the important Arab translator Ḥunayn ibn Isḥāq (807–873 CE) collected his Greek manuscripts from all over the Middle East; he did not have to request them from the Byzantines (Strohmaier 1994). This does not exclude the possibility that Caliph al-Maʾmūn (r. 813–833 CE) endeavored in his diplomatic correspondence to fill several gaps in the inventories of his "House of Wisdom," including the futile attempt to lure to his court the Greek philosopher Leo, who lived in poverty in his home country (Lemerle 1971, 148–154). Even though his experts in astronomy, mathematics and geodesy were so advanced that they probably had nothing left to learn from the Byzantine scholar,[4] in my opinion having a native speaker of Greek, especially one who mastered the nomenclature, would have been useful in studying the works of the Ancients. Episodes of this kind still cannot alter the general depiction of an autochthonous stream of Ancient scientific education that had not yet run dry.

13.4 Autochthonous Greek Learning versus Indian Science

As a martyr of philosophy, Socrates was an iconic figure for many intellectuals; the notorious Abū Bakr Muḥammad ibn Zakarīyāʾ al-Rāzī (around 854–925 or

[3] Cf. (Endreß 2004, 2).
[4] So, certainly justifiably (Gutas 1998, 180).

935 CE), known in the Occident as Rhazes, a heretic who deemed all prophets of the revealed religions to be frauds, had even chosen him as his imam (Strohmaier 1997) and the name Suqrāṭ appears along with two apocryphal sayings on a mausoleum in the Street of Tombs of Shāh-i Zindā in Samarkand (Strohmaier 1993). The military campaigns of Maḥmūd of Ghazna presented al-Bīrūnī with the opportunity to study the religion, customs and also the sciences of the Hindus. He came to the conclusion that these were generally inferior to those of the Greeks. The compromises which Indian astronomers entered into with their folk religion made him aware of their lack of a Socrates who was ready to die for the sake of truth.[5]

Figure 13.1: Preface to the Zij (astronomical book) of Ulugh Beyg produced in Samarkand ca.1440. From the Art and History Collection at Arthur M. Sackler Museum, Washington DC.

In Baghdad there was initially a sort of competition with Indian science, sponsored by the courtiers of Persian ethnicity. Of particular prominence are

[5]See (al-Bīrūnī and Sachau 1925, 12, 16–18, 256.21; Strohmaier 2002b, n°s 55 and 62).

the activities of the mathematician and astronomer Abū Jaᶜfar Muḥammad ibn Mūsā al-Khwārizmī (around 800–847 CE), who, as the name states, came from Khwarazm, but worked during this early period at the "House of Wisdom" in Baghdad and propagated Indian algebra. Over the course of time the modest Indian contribution was increasingly marginalized by the Greek elements, even in Central Asia. Oddly enough, the Indian heritage was perpetuated best in Spain, as can be seen from the Latin translations produced there, which preserve some of what was lost in the Arabic originals (Strohmaier 1992). Not even the system of Indian numerals was able to propagate among Muslim scholars as would be expected. They remained true to the Greek alphabetic system. Ibn Sīnās's attentive father, who wanted his son to learn everything, sent him for this instruction to a greengrocer at the market (Gohlmann 1974, 20–21), where the practical method was better established. Ibn Sīnā's tutor al-Nātilī, with whom he studied Aristotelian logic and Euclidean mathematics, apparently did not feel responsible for teaching this subject.

It may seem surprising that Chinese philosophy and science did not have any visible influence on Central Asian thinking despite the geographical proximity of trade ties via the Silk Road. What did arrive were individual commercial goods and at best the stories associated with them for the purpose of promoting their sale. Included under the keyword "tea" in al-Bīrūnīs's *Pharmacognosy* is a legend relating how the beneficial effect of the plant was discovered by an imperial official.[6] Even he, a native of Khwarazm, shared the prevalent opinion that there was only one nation to the East with a proclivity for science, namely India (Strohmaier 2008, 243f.).

13.5 The Role of the Courts

Well into the Modern Age there was no foundation of institutions in Islam comparable to the Ancient School of Alexandria or our universities (Makdisi 1981, 75). The setting for the cultivation of worldly sciences was the courts, which had flourished and multiplied over the course of feudal fragmentation. A good comparison is the proliferation of small states in eighteenth-century Germany and the Weimar minister of state and poet Goethe, although as a leading natural scientist of his time he was able to maintain connections to a university, the one in Jena. Of course, this created a precarious situation in Islam, where much depended on the person of the monarch and the constraints placed upon him by the masses and their orthodox spokesmen. This was the case in Cordoba, for instance, where the philosopher Ibn Rushd (1126–1198 CE), known in the West as Averroës, was banned; he went on to become an influential commentator of Aristotle in Latin scholasticism, an achievement denied him by the subsequent generations of Muslim thinkers.

[6] See (al-Bīrūnī and Karimov 1973, n° 237; Strohmaier 2002b, n° 85); cf. (Strohmaier 1978).

The spontaneous assemblies at the court of scholars with various areas of interest can be designated as academies in the contemporary sense. The biography of Ibn Sīnā contains a vivid depiction of the circumstances in Isfahan under the auspices of Alāʾ al-Dawla, who was decried as a libertine by the orthodox.[7] Particularly favorable conditions existed under the reign of the Maʾmūnids in Khwarazm, who ruled as the Khwarazm Shahs from 995 until 1017 (Bosworth 1978b, 1066). The manifold relationships between the individual scholars can be inferred from the manuscripts, which bear mutual dedications. It would be a rewarding task to compile lists of who dedicated what to whom. Even though not all texts have survived, in many cases we have the bibliographic notations documenting these interrelationships. At the same time, these dedicated manuscripts are an indication of the oral exchange that can be presumed, but which is reported only in exceptional cases. Worthy of particular mention is the role of the vizier and patron Abū l-Ḥusayn Aḥmad al-Suhaylī, to whom an especially great number of manuscripts were dedicated by grateful scholars. Ibn Sīnā committed to him a treatise on the subject of why the Earth stands still at the center of the cosmos (Gohlmann 1974, 149, n° 44). It may be presumed that this very issue had been challenged in preceding debates. However, these concerned only the possibility of rotation at a stationary position, not an anticipation of the Copernican Revolution. In Ghazna, Afghanistan, al-Bīrūnī dedicated an *Introduction to Astrology* to an otherwise unknown woman by the name of Rayḥāna, who came from Khwarazm like himself (al-Bīrūnī and Wright 1934).

A choice example of such a disputatious exchange is the correspondence between al-Bīrūnī and Ibn Sīnā about questions of Aristotelian natural philosophy, which they conducted until Ibn Sīnā came to Khwarazm on his flight from Bukhara. It is remarkable in terms of their worldview, as al-Bīrūnī adheres to the creationism of the Koran, while Ibn Sīnā advocates a neo-Platonic Aristotelian theory of the world's eternity.[8] This was connected with the question as to whether the heavenly spheres are also subject to changes, which al-Bīrūnī holds to be possible, pointing out that in the mountains, too, such changes cannot be observed in real time with the naked eye. The correspondence also includes a purely historical discussion of the role of the Christian professor John Philoponus, who had taught in Alexandria five hundred years before.[9] This demonstrates the continuing vibrancy of the heritage of the School of Alexandria.

As intellectual centers, the courts in the East as in the Spanish West presented successful competition to the caliphate capital of Baghdad, and thus it was not unusual for experts to leave the capital to seek accommodation elsewhere, as for example, the Christian scientist and translator from Syriac into Arabic Abū l-Khayr al-Ḥasan ibn Suwār ibn Bābā ibn al-Khammār, who accepted the call of

[7] See (Gohlmann 1974, 64f.; Strohmaier 2006, 37–39).
[8] See (Naṣr and Muḥaqqiq 1972, 12.7–13.1, 19.9–20.3, 51.13–52.10, 53.16–54.8; Strohmaier 2002b, n°s 6 and 7).
[9] Cf. (Sambursky 1965, 571–597).

the Khwarazm Shah Abū l-ᶜAbbās Ma'mūn II (Kraemer 1986, 123–130). From Gorgan on the Caspian Sea came the physician Abū Sahl ᶜĪsā ibn Yaḥyā al-Masīḥī, also a Christian, as the name reveals. He wrote a handbook of medicine for the above-mentioned vizier al-Suhaylī (Ullmann 1970, 151; Karmi 1978, 271–273).

The role of the courts, even in the late nineteenth century, can be inferred from the example of Bukhara, where the scholar—and intimate of the Emir—Aḥmad Makhdūm Dōnīsh (1827–1897) was able to predict a lunar eclipse, while the clerical teachers at the madrasah Miri Arab denounced this as the work of the devil, or so it was depicted in the perhaps slightly exaggerated satire of the *Memoirs* of Sadriddin Ayni, the founder of the modern Tajik literary language (Ayni 1953). Moreover, these teachers were experts on Aristotelian logic, which they cultivated in a fatuous and tedious manner (Strohmaier 1983). This was one of the many examples for the general decline of intellectual life in the Muslim world.[10]

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[10] About the probable causes, cf. (Strohmaier 2002b; Cosandey 2007, 321–370).

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Chapter 14
The Sciences in Europe: Transmitting Centers and the Appropriating Peripheries

Manolis Patiniotis and Kostas Gavroglu

14.1 Introduction

It has been commonly the case that while discussing the transmission of the sciences to regions outside Europe there is ample reference to "European science," implied as a unified whole of ideas and practices from more or less the seventeenth century. If what is meant by European in this expression is a purely—and, yet, ill-defined—spatial reference, then there is not much one can disagree with. But if European signifies or encapsulates the historicity of a specific stage in the development of the sciences, then to consider "European science" as something unified is grossly misrepresenting what happened during the eighteenth and part of the nineteenth centuries in many localities of what has been constituting geographical Europe: Spain, Portugal, Russia, the Scandinavian countries, the western regions of the Ottoman Empire including Greece, Bulgaria, Serbia, Romania and so forth. What we would like to argue in this paper is that a study of the globalization of knowledge cannot be properly understood without the study of the Europeanization of knowledge—especially for part of the seventeenth, all of the eighteenth and part of the nineteenth centuries. And a crucial aspect for the comprehension of the processes involved in the Europeanization of knowledge is a methodological/historiographical shift: to move away from considering these processes as processes of transmission/transfer of ideas and practices from the "center" *to* the "periphery," and adopt, instead, the view of appropriation of ideas and practices *by* the "periphery." Hence, realizing a shift from the view of a relatively passive "emitter" whose preoccupation is the transmission of ideas and practices—more or less intact—over short or long distances, to the view of an active "receiver" whose problem is how to appropriate new knowledge to the local context.

The history of the transmission of scientific ideas from the "center" to the "periphery," especially during the last five centuries, is a subject that has drawn the attention of historians long ago. In recent years Europe went through profound transformations and these changes created a new context for the re-examination of a host of issues, some of which have been associated with the transmission of the sciences. New nation states came into being, new borders emerged, new institutions appeared, and old institutions have been restructured. These changes have induced many scholars to look again at Europe's past, and the history of science is one of the subjects to be systematically examined. The work that has already been done, as well as newly available sources combined with a more open intellectual environment and increases in funding for transnational and transcultural contacts offer an unprecedented opportunity for a critical re-examination of the historical character of science and its institutions in European regions and societies for which little or no work has been done. And it is in this context that historians have been able to articulate a number of new questions: How should we try to study the long-standing question of the tension between particular local practices and the progressive homogenization of an international scientific community? How was this tension particularized within the framework of a Europe aiming to dictate global policies, while at the same time facing the shifting of boundaries among its nations and cultures? To what extent was each local society willing to receive the new sciences and provide them with the appropriate institutional background? To what extent were local scholars willing to adopt the particular corpus of ideas and to organize their collective intellectual activity on its basis? To what extent did scholars, philosophers or scientists originating in a specific society participate in the formation of scientific ideas in the respective scientific centers? And, in addition, how should we deal with the old problem of the transfer of scientific knowledge in a historiographic context offering a great variety of approaches?

The attempts to answer these questions set a new framework for the discussion of the "local" in history of science. How does the "local" integrate into the "universal"? Through which processes were local intellectual and institutional contexts incorporated into the dominant scientific ideal? What was the role of the local cultural traditions in the building of a uniform European scientific culture? Historians dealing with these questions aim at promoting the study of local issues avoiding the pitfalls of the received heroic accounts. They also aim at exchanging information and methodological contemplations in order to examine to what extent the "view from the periphery" might bring a new perspective to the history of science in general.[1]

In what follows we shall present the development of "Greek science" during the eighteenth century, as a characteristic case reflecting many of the issues involved in the above questions. At the same time, we shall try to show how a shift from

[1] Such recent undertakings are STEP ("Science and Technology in the European Periphery") and the "Tensions of Europe." The former is a group of historians of science from many European countries (Belgium, Denmark, Sweden, Finland, Russia, Turkey, Greece, Italy, Spain, Portugal and Hungary) who study the circulation of scientific knowledge between European centers and peripheries from the sixteenth to the nineteenth centuries. See www.uoa.gr/step and (Gavroglu et al. 2008) for a historiographic review. "Tensions of Europe" is a network of historians from seventeen countries who explore transnational European history with a focus on the roles of technology as forces of change. Their main tenet is that examining the European integration through the lens of technology will make visible a bottom-up "hidden integration" and provide a deeper and richer historical understanding of the process. See www.tensionsofeurope.eu. Concerning the scope and the historiographic perspective of the group, see (Misa and Schot 2005; Schot et al. 2005).

the dominant approach of "reception studies" toward a historiography focusing on the processes of appropriation might offer us a clearer view of some important aspects of the Europeanization of knowledge.

14.2 Historical Background

In the eighteenth-century Balkans various social formations started coming into existence as a result of the intricate historical process prompted by the decline of the Ottoman Empire. Modern Greek society was one of these formations (Mazower 2000). Demographically this society consisted of many different populations dispersed within and outside the borders of the Ottoman Empire. The elements that played the most prominent role in unifying these populations were basically cultural and ideological: Christian Orthodox faith and Greek-speaking education. This was a result of the political arrangements that followed the Ottoman conquest of Constantinople three centuries earlier.

Immediately after the fall of the city in 1453, Sultan Mohammed II appointed Georgios Gennadios (ca. 1400–1472) the new Patriarch of the Orthodox Church and provided him with a written "privilege" that granted the Christian authorities jurisdiction over many aspects of the religious and civil life of the Christian populations of the Balkans and Asia Minor. The Sultan's decision was a highly symbolic gesture aiming to respond to the complications related, on the one hand, to the administration of a continuously expanding empire with a progressively increasing Christian population and, on the other, to the threat from Christian Europe: At a time when "nation" meant an aggregation of people who shared the same religious beliefs and attended the same rituals, the Orthodox Patriarchate was the only institution which was in a position to present a more or less unified expression of the various Christian populations to the Ottoman administration. At the same time, Mohammed took advantage of the deep animosity between the Orthodox and the Catholic Churches, which progressively strengthened after the schism of 1054. The choice of the Orthodox Patriarch as the de facto political representative of the Christian populations of the Balkans, and his favorable disposition toward those who opposed the reunification of the Churches (in contrast to many influential Byzantines who were in favor) was a shrewd decision aiming to undermine any prospective alliance of the Christians in the Ottoman Empire with those in Europe. In the course of time, it turned out that Mohammed's arrangements contributed to a long-lasting social stability in the eastern Mediterranean and the Ecumenical Patriarchate was integrated into the Ottoman administration as a state institution, exerting power over a great number of Christians dispersed throughout the vast territory of the Ottoman Empire. Thus, the power of the Patriarchate was not only religious but also political and economical.

One of the most important consequences of this arrangement was that it allowed the Patriarchate to ascertain control over the educational activities of these populations. For a long time, however, education was very poor, since its basic aim was the (re)production of medium rank clergy. According to all (but to be sure, quite limited) extant evidence (Psimmenos 1988, 174), the school curricula of the sixteenth century included Aristotle's logic and rhetoric, and the patristic tradition of the Eastern Church. The first significant revival of philosophical thought took place in the years of the Patriarch Kyrillos Loukaris (1570–1638), who appointed the Neoaristotelian philosopher Theophilos Korydaleus (1563/74–1646) director of the Patriarchal Academy. Loukaris' aim—triggered by the activities of the Jesuits in the Eastern Mediterranean—was to promote the shaping of an intellectual identity for the Orthodox populations of the Ottoman Empire, which would render them a discreet cultural entity between the Muslim East and the Catholic West (Hering 1968). Korydaleus was the first scholar after the fall of Constantinople, who introduced a systematic interest in Aristotle's physics and brought forth the works of the Greek-speaking commentators of the past. He wrote extensive commentaries of his own on *Physica* and *De generatione et corruptione* drawing upon the commentaries of Alexander Aphrodisieus and the views of the Italian Alexandrists of the sixteenth century (Tsourkas 1967; Schmitt 1984). His work was not favorably received by some of his contemporaries, since such views expressed a covert materialism, but it enjoyed the protection of the Church as it was the only available antidote to Catholic scholasticism. As a result, it formed the core of higher philosophical education for more than 150 years and had a long-lasting impact on Greek intellectual life.

The physiognomy of education and the respective features of intellectual life were further defined by the subsequent social developments in the Ottoman Balkans. The early eighteenth century witnessed the emergence of the Phanariots, a group of Greek-speaking noblemen who simultaneously served at the court of the Ecumenical Patriarchate (situated in the Phanari region of Constantinople, hence the name Phanariots) and of the Ottoman administration. From the end of the seventeenth century, the Phanariots acquired an increasingly important role in the administration of the Ottoman state. At the outset of the next century, representatives of the Phanariots were appointed by the Sultan as governors of Wallachia and Moldavia. The Phanariots would soon take the lead among all the other Orthodox groups of the Balkans. As administrators and diplomats they adopted the line of enlightened despotism. Their political dominance reinforced the already strong influence of the Greeks in the economic and cultural sphere of these regions. The Phanariots played a significant role in the secularization of education by promoting the establishment of schools and by favoring the introduction of contemporary European trends in education, as well as in social life. Especially in Constantinople, Bucharest and Jassy, their presence was rather emphatic, but they also intervened in educational matters elsewhere either by offering protection to particular scholars who built their careers on modern philosophy or by contributing to the building of new schools, which aimed at the wider public.

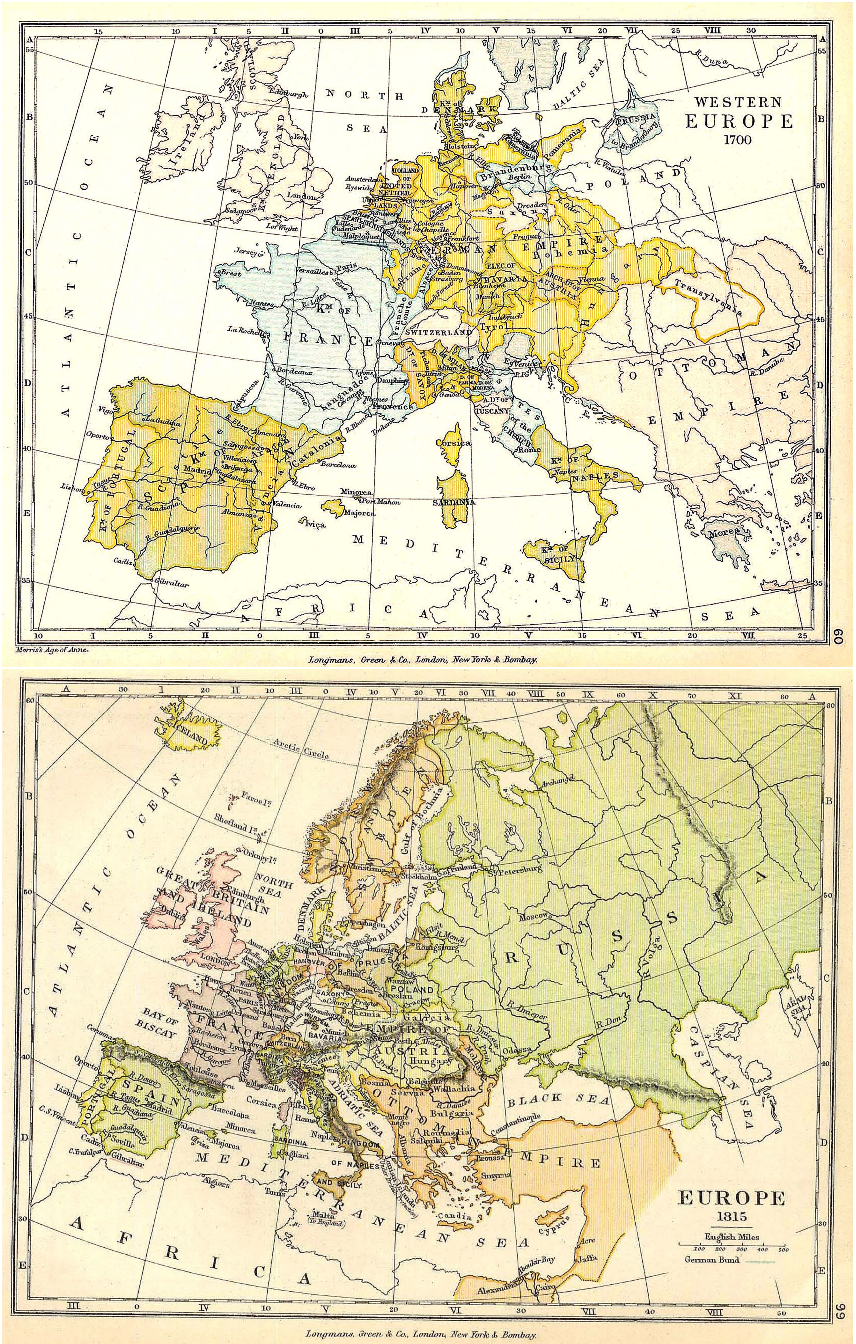

Figure 14.1: Europe has always been a changing landscape. So too were the flows of knowledge that shaped “European science.” University of Texas Libraries.

At the same time, another social group sought to secure its share in the distribution of social and economic power among the Orthodox populations of the Balkans. It was the group of wealthy craftsmen and merchants of Epirus, western Macedonia and Thessaly. The area had a long tradition in commercial and handicraft activities, but it also comprised the most important migration center of the Ottoman Empire. In fact, it was the gate that connected the Ottoman territories with the European commercial routes. The populations of the area traditionally served as intermediaries in this communication, and many people over many generations immigrated to central Europe in order to establish or maintain the links of this commercial network (Stoianovich 1960; Cicanci 1986). The area gradually became an educational center, since the wealth and the size of the local communities allowed them to establish many new schools. Moreover, in the course of their self-assertion and due to the distance from the traditional political and educational centers, the communities encouraged the creation of an intellectual atmosphere, which was quite receptive to the new educational and philosophical trends of European thought. It is important to stress that most Greek-speaking scholars who dealt with the sciences and the new natural philosophy during the eighteenth century originated in this narrow area of the south-western Balkans (Patiniotis 2003).

All these developments did not alter, of course, the basic features of educational activities and, most importantly, the predominance of the Church in educational matters. Both Christian faith and Greek-speaking education, the two elements that unified such different groups as the Phanariots of Constantinople, the Vlach merchants of Epirus, the Greek fraternity of Venice, the Greek-speaking immigrants of central Europe and the administrative elite of the semi-autonomous Danubian regions, were under the jurisdiction of the Ecumenical Patriarchate of Constantinople; but, in light of the developments that took place in the eighteenth century, both elements were now also heavily tinged by the particularities of the various local communities. This was particularly important for education, because due to the lack of other (state) institutions, Greek-speaking education became the main intellectual space that hosted all kinds of fermentation, negotiations and collective pursuits concerning the political and intellectual identity of the emerging society. This was also the context wherein the assimilation of the new natural philosophy took place, during a long period, which spans from the late seventeenth century until Greece won its independence in the late 1820s.

From the outset of the eighteenth century, Greek-speaking scholars began to disperse throughout Europe, and Padua ceased to be the almost exclusive place to study. They also began to travel to the German states, the Low Countries, Russia, the Habsburg Empire, and—to a much lesser extent—to France and England. They were thus acquainted with a multitude of intellectual traditions and schools, related mainly to the recent developments of the various movements of Enlightenment in Europe. When these people returned to their homelands, after having spent from four to ten years in the European educational centers, they strove to gain social recognition corresponding to their intellectual qualifications. The quest for modernization of certain local societies formed the ground upon which their social aspirations could flourish. The young (or not so young) scholars perceived themselves, and were also perceived by others, as agents of a new spirit in Greek intellectual life. Far from serving a homogeneous program of modernization and far from having gained the general consent of the local authorities, they were considered the agents upon whom the most dynamic social groups counted for the shaping of their collective physiognomy. But the constituents of this physiognomy were still under negotiation. As a result, the Greek-speaking scholars of the time found themselves at the intersection of multiple cultural traditions and social interests. The textbooks they wrote and the philosophical discourses they elaborated reflected their aspirations in this ambiguous situation (Patiniotis 2003).

14.3 Newtonianism in the Greek Intellectual Context

The introduction of Newtonian ideas into the Greek intellectual space took place basically in the second half of the eighteenth century. During that period, a great number of textbooks were written and published for the use of students in higher education. Many of them were devoted to such practical issues as arithmetic, geography and "commercial science." But a significant number was also devoted to more theoretical and contemplative issues, like metaphysics and natural philosophy. With only one unique exception, all these works could be more or less characterized as "Newtonian."[2] Naturally enough, the training and the resources of the authors played a decisive role in the character of their intellectual production.

Many eighteenth-century Greek-speaking scholars spent a significant period of time in important European universities. As already mentioned, since the seventeenth century, the dominant tradition was to attend the university of Padua and, to a much lesser extent, other Italian universities. As the decades went by, though, one can observe a shift toward German universities, as well as a turn of the intellectual focus toward German-speaking centers: Vienna, Leipzig, Jena and Halle. In either case, Greek-speaking scholars had the opportunity to be actual witnesses of various discussions and disputes concerning a number of issues in Newtonian philosophy. They also seem to have been well acquainted with the bibliography and the published sources of the time. This broad view over the Newtonian natural philosophy is clearly reflected in their works. Some directly translated renowned treatises, which promoted the spread of Newtonian ideas in Europe, like Benjamin Martin's *Philosophical Grammar* (Gazis 1799), Petrus van Musschenbroek's *Elementa physicae conscripta in usus academicos* (Theotokis 1766, 1767), Joseph Jérôme Lalande's *Astronomie* (Philippidis 1803) and Francesco

[2] The unique exception is the two polemical books written by Sergios Makraeos, one criticizing the introduction of the heliocentric system (Makraeos 1797) and the other—twenty years later—attempting to restore Aristotelian physics (Makraeos 1816). Interestingly enough, the former employs a certain interpretation of the Newtonian concept of central forces in order to prove the instability of the heliocentric system.

Soave's *Instituzioni di logica, metafisica ed etica* (Konstantas 1804). Others translated older texts bearing a relevance to the main themes of their contemporary natural philosophy, like Fontenelle's, *Entretiens sur la pluralité des mondes*, whose translator appended a long list of notes turning the originally Cartesian text into a Newtonian confession (Kodrikas 1794). But most of them used a great number of sources—often without mentioning them—in order to select views, findings, proofs and information to build their own natural philosophical accounts. In such cases, the Greek-speaking scholars would enter a dialogue with some of the most widespread resources of the Newtonian trend: Samuel Clarke's publication of his *Correspondence* with Leibniz and his famous annotated translation of Jacques Rohault's *Physics*; Willem Jacob van 'sGravesande's *Physices elementa mathematica* and his *Introductio ad philosophiam*; Émilie du Châtelet's, *Institutions Physiques*; and, of course, Voltaire's, *Éléments de la philosophie de Newton.* There is significant evidence that some of the authors might have read Newton's own original texts,[3] but most of them contented themselves with treatises elaborating on various aspects of Newtonian philosophy. In this respect, an important resource for their scholarship was the *Encyclopédie*, which provided them with concise and comprehensive accounts on the latest developments in the field (Rigas 1790; Kodrikas 1794).

How is one to assess the receptiveness of Greek intellectual life toward the Newtonian philosophy of the time? Most Greek historians concentrate on an attempt to record the various Newtonian doctrines, which occur in the works of the Greek-speaking scholars, taking them as signs of a changing attitude toward modern science. According to these historians, the reference of a number of Newtonian tenets or the subscription to the mechanical worldview indicates the willingness of the scholars to break with the dominant Aristotelian tradition and embrace the new natural philosophy. Thus, taking "Newtonian physics" as a more or less coherent synthesis, they organize their research around the examination of how fully and how faithfully the various aspects of the Newtonian worldview were represented in the Greek books of the time.[4] Very often, however, the conclusion they reach is that, notwithstanding the ideologically favorable attitude of many Greek-speaking scholars toward the new natural philosophy, the degree of "scientific" sophistication of their works is rather limited!

One issue that has actually puzzled historians about the intellectual attitude of eighteenth-century scholars is their views on experiment. In the eighteenth century, Newtonian philosophy was almost synonymous with experimental philosophy and many proponents of the new natural philosophy, like Benjamin Martin,

[3]Especially *Optics*. See, for example, (Voulgaris 1805b, part 2, 155, Voulgaris 1805a, 38–41), where the description of the atomic system closely follows "Query 31." The same author, who was one of the most erudite scholars of the time, also cited some important passages from the *Principia*. In (Voulgaris 1805a, 98–99), he quoted the laws of motion directly from the first book of the *Principia*, while a few pages earlier (41–42), when discussing the hypothesis of ether, he cited Newton's views directly from the *General Scholium*.

[4]Indicatively: (Kondylis 1988; Vlachakis 1996; Karas et al. 2003).

Petrus van Musschenbroek and Wilhelm Jacob van 'sGravesande worked to spread Newton's reputation on this front.[5] In consonance with this trend, Greek philosophical and scientific books contained a great number of references either to specific experiments or to the value of experimental study of Nature in general. Moreover, through explicit references to Newton's "rules of philosophizing," they invited their readers to endorse the experimental method as the proper way to conduct empirical investigations.[6] Beyond such an acknowledgment, however, we have no evidence about actual experiments conducted by Greek-speaking scholars. They mentioned experiments made by others, they commented on remarkable observations made in European laboratories and observatories, they argued for the acquisition of experimental devices to be used in Greek schools and they declared their adherence to the new empirical method of investigation as opposed to the infertile scholastic explanations; but, as far as we know, they did not seem to have systematically conducted actual experiments (Karas et al. 2003, 514–555). At most (and according to scarce evidence) they organized some experimental demonstrations for the elucidation of their students or maybe of a wider learned public. The heuristic role of experiment and its instrumental use in the quantitative investigation of the external natural world was outside their scope and it did not appear to be part of the discourse they attempted to form.

Similar things hold concerning the mathematization of natural philosophy. Newtonian mechanics (in the beginning, a part of mathematics itself) marked the convergence of natural philosophy with mathematics. Especially due to the fact that Newton's major intention was to study the generation of celestial trajectories, mechanics was prompted to cross the border of pure quantification and enter the realm of dynamics. Geometry could not accompany natural philosophy along this venture; the redefinition of space, time and motion went hand in hand with the introduction of calculus as the backbone of rational mechanics (Cohen and Whitman 1999, 382; Patiniotis 2005, 1634–35). This characteristically Newtonian approach is totally absent from the eighteenth-century Greek scientific treatises. Greek-speaking scholars were well versed in mathematics and had produced a number of treatises on Euclidean geometry, the conic sections and the modern developments in algebra. In neither case, though, did they link the developments in mathematics with the developments in mechanics that had fueled them. On the contrary, the treatment of the fundamental notions of the new natural philosophy retained a high degree of metaphysical sophistication in their works. Quite a few scholars ventured into novel syntheses, crossed multiple traditions and employed a highly technical vocabulary, but they persistently avoided getting involved with the mathematical technicalities of rational mechanics. The instances of clear mathematical treatment of dynamics were scarce and even these very soon turned to the trivial problems of Archimedean or Galilean mechanics. On the other hand, the emphasis put on the elucidation of the readers through empirical examples

[5]See, however (Schaffer 1989).
[6]See (Theotokis 1766, 7–10; Voulgaris 1805a, 6; Koumas 1807, Vol. 4, 230–231).

drawn from everyday life is significant, indicating the authors' desire to handle the new natural philosophy in a primarily qualitative way.

The ambiguous relationship of Greek-speaking scholars with experimental philosophy and mathematics forms part of a broader historiographic discussion concerning the kind of natural discourse developed by these scholars. According to many historians, Greek science lacked originality and creativity. It was a vague reflection of the developments that took place in the centers of the Enlightenment, used in the Greek context primarily for ideological purposes. However, due to the Ottoman rule over the Greek-speaking populations of the Balkans, even the mere attempt to bring Greek education in contact with Enlightened Europe is considered a heroic endeavor. Against this background, some historians have developed the argument that the assumedly low level of the philosophical and scientific production of the time reflects the real conditions of the specific society, and thus the question of originality is literally and metaphorically untimely (Psimmenos 1988, 31). Others consider that Greek-speaking scholars might not be the kind of natural philosophers who could be met at the time in Western Europe, but when they decided to convey the new knowledge to their particular intellectual space, they went through a selection process, adapting this knowledge for educational use (Karas 1991, 89). The fact itself that, irrespectively of the degree of sophistication, specific scholars assimilated and spread the new scientific spirit in the Greek intellectual space, countering popular ignorance on the one hand, and the established authorities on the other, was not only important for the revival of the Greek intellectual life, but also determined the subsequent political and ideological developments until the Greek war of independence.[7] Indeed, a most characteristic aspect of the historiography holding these views is that it persistently links the introduction of the sciences with the enlightenment of the "nation" in anticipation of national emancipation (Karas et al. 2003, 48 (esp. n. 9), 49–50, 74). In any case, however, the latent premise behind such considerations is that Greek-speaking scholars were, at best, enlightened teachers. Due to particular historical circumstances, their intellectual activity was confined to the limits of education, and this confinement marked decisively the character of their scientific and philosophical production. For reasons that did not depend on their will or their capabilities, Greek-speaking scholars were unable to share the creativity of modern European thought, but one should properly appreciate the pedagogical and ideological consequences of their work.

14.4 Centers and Peripheries

The agenda of most historians who study eighteenth-century Greek intellectual life draws heavily upon the idea of *transfer*. "European science" is an idealized entity and the study of the Greek scientific and philosophical activity primarily focuses on how successfully the attainments of European thought were transferred to a

[7] See the introduction in (Henderson 1970).

culturally underdeveloped and scientifically uninformed context. Greek historians are not alone in this. For the last thirty years, the distinction between centers and peripheries has been widely applied in history of science, and Greek historians, like many other historians in the "periphery," became part of this general trend. Most of the studies produced in this area aimed at the investigation of the cultural aspects of the receiving environments, which *facilitated* or *undermined* the expansion of the sciences, or even *distorted* the scientific ideas in their way from the "original" source to the final recipient. Notwithstanding the problematic aspects of the center-periphery dipole, pointed out by many scholars, the leading idea in most of these accounts was that real science was produced in specific scientific centers and, subsequently, thanks to its indisputable truthfulness and its widely appreciated usefulness, it forcefully imposed its presence on the rest of the civilized world.

The center-periphery model was first introduced in 1954 on the occasion of the United Nations economic survey of Europe (Despicht 1980). The model was used in order to depict the differences in economic and political structures between the industrialized and the less or non-industrialized countries of Europe. According to this model, the countries that constituted the center have been the suppliers of capital and technology, while at the same time, they functioned as providers of tourists and absorbers of migration. As a result, a major characteristic of the periphery has been its dependence upon the center (Selwyn 1979). Critical decisions related to the economic potential of the former have been taken in, or entirely influenced by, the latter. Moreover, because of the lack of local innovation, peripheries have been presented as importers of "new products, new technologies, new ideas," which emanated from the centers and were transferred to the periphery by means of migration.

The above scheme conveniently served for many years the fields of economic and political theory. Serious problems emerge, however, when it is used as a *historiographic* scheme. The last thirty years history of science witnessed the emergence of a whole thematic area, which is known as *reception studies.* The purpose of most works produced in this area has been to examine the spread of the scientific and technological attainments in areas that did not originally participate in the shaping of the respective ideas and practices. The term "reception studies" is often used to denote that there is something (a science, a scientific theory, a technological innovation) which was formed in a certain social and intellectual environment (a center of scientific or technological production) and, thanks to its inherent dynamics (its explanatory efficiency, its emancipating power, its undeniable usefulness), spreads in other environments, very different from the one where it first appeared. A significant number of historical works have been produced according to this model: The spread of the scientific ideas of the Enlightenment in the periphery of Europe, the introduction of modern astronomy in China, the reception of Darwinism in various cultural contexts, and, of course, the intricate relations of science and technology with imperial and colonial policies.[8]

In most of these studies, the factors that define the character of the exchange between center and periphery are two: The *way* in which the representatives of a certain intellectual milieu came into contact with the "other"—be it Newtonian physics, steam technology or the Darwinian theory—and their *attitude* to it. Concerning the former there is a huge variety of means: Missions, which traveled to China bringing new scientific and technological knowledge; scholars from the periphery of Europe who traveled to the countries of the center in order to participate in the new scientific developments; colonial invasions, which established scientific elites in the countries they controlled; networks of scientific correspondence, which connected remote places across the European continent; even an emperor traveling around Europe to get acquainted with the fruits of modern science and to enroll the most brilliant natural philosophers, mathematicians and engineers to his peripheral court in Saint Petersburg. Concerning the latter, however (the attitude of the local actors toward the new ideas), the variety of means is significantly smaller: There were always those who adopted the new scientific ideas and were willing to back the changes resulting from their social incorporation, and those who reacted to their adoption upholding the social and intellectual values related with the locally dominant beliefs and practices.

The kind of scientific activity that was eventually established in the receiving environment is usually described as the outcome of such confrontations. In many cases the confrontation was resolved either through institutional initiatives—the establishment of academies, universities or laboratories, which accommodated the new scientific activity—or thanks to certain social developments that favored the establishment of the scientific community and the respective interest groups, which took advantage of the new science.[9] In other cases, the confrontation spanned a long period of social imbalance and came to an end only thanks to a deep social transformation.[10] In almost all cases, however, the stake is the same: The extent to which the particular confrontation favored or inhibited the establishment of a new science or the extent to which it resulted in the distortion of its principles during the transfer from the place of its birth to the receiving environment.

[8] Indicatively: (Basalla 1967; Goodman 1988; Cueto 1989; Polanco 1989; Lindqvist 1993; Todd 1993; Santesmases and Muñoz 1997; Lértora Mendoza et al. 2000; Ihsanoğlu 2004).

[9] This was, for example, the case of Coimbra University and of the Royal Academy of Science in eighteenth-century Portugal (Simões et al. 1999), of the scientific and educational reforms of Peter the Great in eighteenth-century Russia (Rieber 1995), and of the Shanghai Polytechnic School, established in the second half of the nineteenth century (Wright 1996).

[10] This is to some extent the case of late eighteenth-century Spain (for the diverse views over this period, see (Nieto-Galan 1999)) and of nineteenth-century Italy (Cerruti 1999). Also of special interest to our analysis is the case of the Ottoman Empire, which first came into contact with the Western sciences at the beginning of a long social transformation, which started in the mid-eighteenth century and culminated with the movement of Tanzimat, between 1839 and 1856. On this issue, see (Ihsanoğlu 2004) and its review (Patiniotis 2006).

It is clear that the above scheme is an immediate outcome of the center-periphery distinction: The "center" produces science and technology and the "periphery," more or less willingly, embraces it in order to consume it; accordingly, the historians' task is to trace the venture of transfer and establishment of the new sciences and technologies from "center" to "periphery." The seeming plausibility of this view provided a kind of legitimization for the historiography which produced it. Had we attempted to apply this approach to the arts the result might have been absurd (Baxandall 1985, 58–62). But concerning science, according to those following this particular approach, things seem to be quite different. The sciences are not subjective expressions of the aesthetic insights of a number of individuals. They represent what exists outside and independently of the individuals, and the role of those dealing with the sciences is to disclose the truths derived from this external reality to the rest of the humanity. According to this particular view, once scientific knowledge has been extracted and formulated, it comprises a kind of commodity which can be distributed by means of the various (mainly intellectual) networks. As a result, scientific centers and scientific peripheries are defined on the basis of the *separation of the production from the distribution of scientific knowledge.*

14.5 New Trends in the Historiography of Science

Recent developments in history of science, however, prompted the shaping of a new frame for the historical study of the sciences in the periphery, which transcends the traditional polarizations. In the context of the new *problematique* the sciences are not perceived as closed systems of ideas and practices responding to the needs of a certain society, nor as self-contained enterprises of natural investigation, to which the various social circumstances simply serve as incentive or interceptive factors. They are mostly treated as cultural phenomena deeply affected by the civilizational patterns of each local context. In this respect, the cognitive traditions and the technical skills are of equal importance to the shaping of a certain scientific discipline as all the other social factors affecting the activity of its agents. Therefore, an important task of a historian who studies the formation of modern scientific discourse is to take into account all the cultural traditions and social conventions which contributed to this process. The purpose of such an approach would not be to show how these factors prompted or prohibited the *discovery* of an indisputable natural truth, but to describe how the inscription of the local traditions and conventions on the structure of the scientific discourse *shaped* natural truth in different places.[11]

Apparently, these methodological developments set a new ground for the study of modern science in the European periphery. The idea that the sciences are not

[11] Probably the most influential study of this historiographic trend is (Shapin and Schaffer 1985). See also (Biagioli 1993). The respective bibliography is quite extensive and displays many differentiations. For a comprehensive overview see, among others (Biagioli 1999).

closed systems, which have been unalterably established in different receiving environments, helps disengage the historiography of science from the pattern of "transfer" of scientific ideas. The questions that arise from this new view of science's history in the periphery predominantly aim at examining the processes through which the new scientific ideas were assimilated by intellectual environments permeated by cultural traditions and social priorities significantly different than those of the environment, which initially gave birth to these ideas and practices. In this respect, the subject matter of historical research should not be the investigation of the factors that favored or prohibited the establishment of the "original" scientific ideas in the periphery, but rather the study of the means employed by each receiving environment in order to incorporate the new ideas and practices into its established social, cultural and educational structures.

The notion of *appropriation* is crucial to this approach. The purpose of a historiography employing this notion is to articulate the particularities of the discourses that were developed and eventually adopted within the appropriating cultures as a result of the scholars' active endeavor to incorporate new scientific ideas in their particular intellectual and social context.[12] Many historians take it for granted that when peripheral scholars introduce new scientific ideas they simultaneously adopt the scientific discourse related to the formation or at least the application of these ideas. But this is not actually the case. The entire enterprise of appropriation of new ideas can be achieved through the formation of a new discourse as the best way of overcoming local constraints. These constraints have to do with the fact that the new ideas usually provide alternative methods and responses to questions to which peoples and cultures *already had adequate answers*. In other words, new ideas are not introduced to be placed in any kind of void; they are always asked to displace other, usually strongly entrenched systems of thought. As a result, the assimilation of the new ideas could not be achieved without the formation of an appropriate legitimizing context (Gavroglu 1995).

It would thus be interesting to see historians direct their attention less to listing which ideas and theories were successfully transmitted to the local intellectual context, and more to the metamorphoses these ideas underwent through the various stages of assimilation. The specific approach is further justified by the fact that when one refers to the early modern period, the homogeneity of such cognitive enterprises as "Scientific Revolution," "science," "physics," or "Newtonianism" is extremely vague. However, the broad discussion about the historiography of Scientific Revolution, for example, as well as the discussions on the multiple aspects of Newtonianism during the eighteenth century have been quite convincing in moving away from the notion of "scientific center" *as a place where a well-defined and uniform scientific enterprise had been consensually agreed upon.*[13] In this respect,

[12]Indicatively: (Ragep et al. 1996; Hard and Jamison 1998; Mazzotti 1998; Rupke 2000; Gavroglu and Patiniotis 2003; Ben-Zaken 2004; Misa and Schot 2005; Patiniotis 2007).

[13]See, for example, (Cunningham and Williams 1993; Cohen 1994; Henry 2002). On the multiplicity and the diversity of interpretations making up the eighteenth-century European image of

the scholars of the periphery were never asked to deal with a homogeneous set of established scientific ideas; they were rather prompted to select from a broad spectrum of scientific and philosophical views of nature those which better expressed their personal preferences. And the scientific discourse they eventually produced was not a poor reflection of an unequivocal conceptual and methodological framework, but an original synthesis, informed by the cultural affinities and the philosophical priorities of their local intellectual context.

Would it be possible, in light of the above *problematique*, to develop an alternative interpretation of eighteenth-century Greek scientific thought? And would such an interpretation be of any use to history of science in general? No doubt, Greek-speaking scholars honored the new celestial mechanics and the new experimental philosophy stemming from Newton's synthesis; they also recorded their findings and praised their cognitive dynamics in their works. But how did they assess the cognitive enterprise of the new natural philosophy? What value did they attach to, and to what extent did they perceive themselves as part of it? The picture one draws from their various statements is that, beyond the manifest praise of the moderns, they perceived themselves as seekers of a deeper kind of natural truth, which would transcend the level of mere appearances and would drive to the heart of Nature's secrets. Theophilos Kairis (1784–1853), one of the most erudite scholars of the early nineteenth century, ventured to give the definition of knowledge. Although this is one of the clearest statements of its kind, one can find a great deal of similar theoretical declarations in the philosophical works of the time:

> Knowledge is the perspicuous understanding of the beings. *Partial* or *individual* knowledge results from individual observations or experiments; *empirical* knowledge results from many such experiments and observations; *scientific* knowledge, finally, is the knowledge which [on top of these] also includes the *reason* of the being and can be combined with other such pieces of scientific knowledge.[14]

Hence, according to this definition, what the moderns did was, at best, "empirical" knowledge, while the goal of Greek-speaking scholars was proper "scientific" knowledge.

Undoubtedly, the Greek-speaking scholars shared with other European scholars the desire to inaugurate an intellectual enterprise that would meet the current condition of philosophy. The question they faced, though, was not about the acceptance or rejection of a new philosophical system about Nature, but about the way they would revive and broaden the scope of their contemporary philosophy. Some European philosophers took groundbreaking initiatives for setting up the new edifice of philosophy: They conducted experiments aiming to unveil

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Newtonianism, see (Patiniotis 2005). For the great variety of social, cultural and symbolic uses of the Newtonian heritage, see (Fara 2002).

[14](Karas et al. 2003, 77); translation and emphasis are the authors' own.

the laws of Nature, which would disclose to them important aspects of the divine design, but only those that God would allow man to get acquainted with. Others formulated mathematically the discovered regularities and expected geometry, algebra and, above all, calculus to lead them to a more secure type of knowledge. Both enterprises were rather distant from the style of philosophizing of Greek-speaking scholars. Neither experimental empiricism nor abstract mathematical contemplation fit this particular style. They were closer to a third group of philosophers who trusted that only metaphysics could lead natural enquiry to a really secure shelter, in the (strictly technical) sense that only metaphysics could provide the proper philosophical devices for causal thinking (Ahnert 2004). Thus, what Greek-speaking scholars basically intended was to upgrade their traditional philosophical context through the incorporation of the most precious pieces of modern knowledge. Apparently, they never intended to incorporate "Newtonianism" as an integrated whole comprising both actual findings and methods of inquiry. Most probably, they did not even perceive it as serious philosophy at all. However highly they esteemed Newton's contribution, new natural philosophy was for them a mode of investigation, which enriched philosophy with new findings, but was in severe need of further philosophical guidance, which would properly accommodate these findings in the traditional (and honored by the ancients) metaphysical discourse about Nature. Thus, they focused on the selection of theories and facts, they even praised the fresh air brought in by the novel methods of inquiry, but they predominantly kept for themselves the role of supervisor, who would lead the road to the final *philosophical* synthesis, *par excellence.* Their philosophical training and the good command of ancient sources, coupled with the knowledge of new scientific attainments rendered them particularly suitable for this intellectual task.

Taking this perspective may significantly change our idea about the intellectual attitude of eighteenth-century Greek-speaking scholars toward Newtonianism. As already mentioned, many historians believe that, although Greek-speaking scholars didn't really embrace the new scientific method, they did their best to propagandize it and, under the specific historical circumstances (Ottoman rule, poor material conditions, lack of proper educational and political institutions), this suffices to offer them a kind of historical vindication. In light of the above discussion, however, it becomes clear that it was not their difficulty, inability or unwillingness to properly *transfer* the new developments that kept them in the periphery of modern scientific discourse. Quite the opposite, they even assumed a *patronizing* role for themselves and it was, actually, this role that resulted in their marginalization as, in the course of time, the claim for a *systematic organization of natural philosophy* yielded to the claim for a *formal organization of empirical knowledge.* In order to understand the relationship of eighteenth-century Greek-speaking scholars with Newtonianism, thus, it is not enough to enumerate the instances of the various Newtonian ideas in the works of the period. This should rather be the starting point for a more comprehensive historical investigation about how the scholars dealt with these ideas, how they *appropriated* them into their familiar philosophical context and what kind of philosophical syntheses they eventually produced.

14.6 Conclusions

Scientific periphery did not preexist the developments in science and technology like an empty receiver waiting to be filled by the attainments of the center. It is rather the outcome of an intricate process, which resulted in the predominance of a certain form of knowledge over other forms of knowledge and cognitive priorities. Thus, historical research should not seek to examine the dynamic confrontation of antithetical pairs like science-metaphysics or center-periphery in the course of history, but to investigate the simultaneous *construction* of such notions and of the respective evaluative indices. Thus, to problematize the category of European periphery in the sciences means to problematize the "self-evident" process that led to the construction of *both* the culture of modern science and the culturally dependent scientific periphery.

Working on the history of science in the periphery does not mean that one should, primarily, aim to do justice to the unsung heroes of the periphery or to restore the contribution of the peripheral countries to the building of the glorious edifice of modern science. Apparently, an important dimension of the work of historians who deal with local issues relates to the unearthing of unknown sources, and to the discussion of the historical circumstances under which modern science and technology were established in the particular context. At the same time, though, periphery is something more than a historical and geographical demarcation: Periphery is also a *historiographic standpoint*. For a long time, the standard narrative in history of science and technology used to take the distinction between center and periphery for granted and to focus primarily on the conditions that contributed to the formation of "original" ideas and practices in the centers and, subsequently, on the conditions that boosted or impeded their spread in the peripheries. Recent studies seem to indicate the obsolete character of such approaches and suggest a more detailed investigation into the circumstances that rendered science and technology a global validity. Starting from the periphery—or better, *standing* on the periphery—might offer a clearer view over the intricate ideological constructs, which accompanied the establishment of science and technology and obscured their socio-political grounding. In many cases, what looked like a complete synthesis when seen from the point of view of the center, was entirely disassembled when it reached the peripheries to become the object of intense philosophical and political consideration.

What did Newtonianism actually mean for eighteenth-century Greek-speaking scholars? Was it a novel philosophical exegesis of Nature? Was it a new method of natural investigation? Was it a set of new findings enriching the traditional philosophical discourse about Nature? Was it a new context for the discussion of such crucial theological issues as God's design of Creation? Was it metaphysics, theology, philosophy, science? Irrespectively of the answers Greek-speaking scholars articulated (and, as expected, they articulated a variety of answers), the study of their work may contribute to further elucidate a period when neither the prevalence of Newtonian philosophy nor the character of the final synthesis could be taken for granted. After all, the story of Newtonianism is not about the spread of Newton's "original" ideas, but about a series of intellectual exchanges, which took place around an original body of ideas, and only after a long and intricate process resulted in what we nowadays understand as Newtonian science. Thus, taking periphery as a historiographic standpoint might help historians bring forward important interactions between different socio-political contexts, which led to the shaping of modern science, as well as the role played by the scientific and technological discourses in the establishment of current cultural distinctions. In this sense, to problematize the category of European periphery in the sciences is neither about periphery itself nor about science and technology *in* the periphery; it is rather about the history of science and technology as part of the globalization of knowledge.

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Chapter 15
The Naturalization of Modern Science in South Asia: A Historical Overview of the Processes of Domestication and Globalization

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15.1 Introduction

The ascent of India as a player in the world of modern science has been a subject of much recent discussion. This paper discusses the institutionalization of modern science in South Asia. The globalization of modern science involved a process of the localization or domestication of modern scientific knowledge and its institutions, as well as an associated process of decolonization that marked the middle decades of the twentieth century wherein the nation state became a contested site for negotiations over the kind of science to be inaugurated in an independent republic (Raina and Habib 2004). Informed by recent developments in the historiography of "post-colonial science" it is argued that this process of domestication of the global was simultaneously accompanied by a process wherein the local was shaped by the global that in turn was reconstituted by the local (Raj 2007).

The study of the globalization of science in non-Western contexts has over the past three decades been shaped amongst other factors by the changing regimes of international politics. The revision of the frames of academic discourse about science in the non-West is more or less concurrent with the process of decolonization initiated within former colonial societies. In particular, post-colonial perspectives of science have been complemented by developments in the sociology of scientific knowledge (Harding 1998; Raina 2007). Consequently, several disciplinary frames engage with the drift produced by the entanglement of the scientific project with that of nineteenth-century European imperialism and colonialism (Adas 1990; Kumar 1995). Science as an essential component of the civilizing mission was in the older perspective the vector of a particular kind of globalization, and its value neutrality ensured its own globalization. The new perspectives reveal the socially embodied nature of scientific knowledge reflected in the manner it is reconstituted in the encounter with other ways of knowing and acting on the world. The meeting of different systems of classification, the process of the cultural appropriation of scientific or technological ideas from one cultural context to another, produced idea hybridizations at the peripheries of modern science (Grove 1995; Raina 1996). This process of hybridization at the periphery stimulated new traditions of research "back home" in the metropolises of Western Europe. The history of modern science in India, it has been suggested, over the last three centuries is on the one hand linked with the arrival of European travelers, missionaries and traders in the seventeenth and eighteenth centuries, and finally the inauguration of colonial rule in the nineteenth century. Under late colonialism it is equally important to recognize that the establishment of scientific institutions and organizations installed before India became independent of colonial rule were linked with the anti-colonial nationalist struggle (Bernal 1942).

This chapter elaborates upon three aspects of the process of the domestication and globalization of science in South Asia. In the first section, the encounter between modern science and the multiple knowledge systems that characterize the South Asian regions is discussed. This encounter is simultaneously both an epistemic one as much as it has been the subject of investigation for the politics of knowledge. The discussion covers the period between the seventeenth and the end of the nineteenth centuries, which marks the century of the encounter between Europe and India and the end of the period marks the reign of the mature phase of colonialism. The second section deals with the coupling of the question of the modernity of science and the modernity of the nation. The trajectories of two distinct projects are entangled. The one having to do with the naturalization or domestication and the expansion of the dominion of modern science and the other with the construction of the modern nation. In other words the modernity of science is entangled with the project of anti-colonial nationalism. And finally, from the 1950s onwards science is harnessed to the projects of development and decolonization in the former colonies. This section traces the evolution of the scientific and technological research system from 1950 until the end of the twentieth century. In the discussion that follows, three terms are apparently employed interchangeably as if they were synonyms for one another, these being 'domestication,' 'naturalization' and 'localization.' However, a clarification is in order. The term naturalization refers to the process of the introduction of plants to places where they flourish but are not indigenous, while the term domestication connotes more or less the same process in addition to which it also connotes "to cause to feel comfortable at home." I have employed these terms to refer to the process of the introduction of modern science into another environment and not to the introduction of plants or animals, but often enough employ them interchangeably. Though it could be argued that the process of domestication involves the additional process of legitimating the knowledge system in another environment. Localization, on the other hand, refers to the process of making local, but where it differs from the other two is that naturalization and domestication could be seen to operate at the semantic level, the process of localization alludes to making new cultural practices local. Consequently, these terms refer to the process of the shuttling that goes on between different knowledge systems as communities of practitioners struggle to make sense of one or the other.

The term knowledge systems has acquired currency in discussions of science and politics over the last three decades, and figures prominently in the literature on the so-called ethno-sciences and the politics and anthropology of science. The idea of South Asian Knowledge Systems is further complicated since the geographic region it encompasses is of continental dimensions and is concomitantly endowed with a multiplicity of cognitive and conceptual schemas that have evolved over time and some of them continue to do so. Furthermore, in the same geographic region more than one "high tradition" could be concurrently practiced with several other "high," "low" or "folk" traditions. It has been variously argued that the Sanskritic, Indo-Persianate, and several "folk" orders entered a phase of rapid institutional neglect and decline between the last decades of the eighteenth century and through the nineteenth century as colonial modernity spread its web across the region (Pollock 2004; Kaviraj 2005). The process of transforming cognitive maps, classificatory and conceptual schemas was accompanied by an institutional decline that in several cases also produced the phenomenon of "disappeared" knowledge systems. In the discussion that follows the term "South Asian Knowledge Systems" will be employed contextually to refer to the computational and astronomical systems, conceptions of the body and medicinal practices as they were practiced in the region, while being embedded in normative orders, linguistic and cognitive frames entailing in terms schemes for abstraction and theorization.

15.2 The Encounter Between Modern Science and South Asian Knowledge Systems

From the mid-eighteenth century onwards, it has been argued, the expansion of the dominion of modern science and European colonial expansion were inextricably linked. We would be committing a gross error of presentism were we to conflate the adventurous forays of European trading companies in South Asia with the full-blown colonial endeavor of the nineteenth century. No matter what the motivations in the two centuries were, European voyagers, missionaries and administrators proceeded with the scientific exploration of the subcontinent and map making since these were closely tied up with the strategic projects of the East India Company and later the colonial state. From the perspective of the history of imperialism the steamboat was easily the most important invention of the nineteenth century. The gunboat and steamship were undoubtedly the most significant technological weapons in the armory of European imperialism (Headrick 1981, 15–19). Furthermore, the cartographic construction of a spatial image of the East India Company's dominion would finally stand in as a representation of the empire itself, conferring upon it a "territorial integrity" (Edney 1997, 2). This construction was deeply inscribed within the imagination of British imperialists and equally among the Indian nationalists by the end of the nineteenth century (Edney 1997, 15). The symbiotic relationship between the spread of modern science and the expansion of colonial power was reflected in the transformation of

India as a British colony into the site of a vast scientific experiment. However, the institutionalization of modern science in India was by no means a mechanistic process but was characterized by a complexity that prevailed upon simplistic ideas concerning the hegemonic imposition of scientific ideas from above.[1]

In the encounter between the so-called traditional systems of knowledge prevalent on the sub-continent and that of the European metropolitan sciences, numerous projects of cultural redefinition in the colonized provinces, in our particular case India, were triggered off. These projects of cultural redefinition were not restricted to domesticating the content of modern science, but generated in a variety of other cultural spheres an interrogation of the foundations of European modernity and a re-examination of what the modern educated Indian elite class began by the end of the nineteenth century to reflect upon as Indian culture (Sarkar 1973). Put differently, Western science had to be reinvented in the idiom of a modernizing India. Broadly defined, the process involved recuperating elements of reason and rationality from within the resources of Indian culture (Sarkar 1973). These processes of localization or domestication or naturalization were epistemically worked through the construction of cognitive homologies that provided the metrics for translating modern science into the language of the existing systems of knowledge and later for revisiting these traditional systems of knowledge through the frame of modern science (Raina 2003). For example, the father of chemistry in modern India, P.C. Ray would forage through the Ayurvedic *materia medica* and, as a trained modern chemist, devise ways of manufacturing Ayurvedic formulations in a company established for the purpose: Bengal Chemicals and Pharmaceuticals.[2] The essence of the project resided in identifying the "active principle" of these Ayurvedic formulations in order to manufacture the "modern equivalents" of traditional formulations—a conception that might have been quite foreign to Ayurvedic pharmacology.

The colonial educational system and its pedagogy and textbooks provide us with interesting insights into the processes of domestication or naturalization. Macaulyan educational policy and colonial diktat triggered the decline of the "traditional" systems of knowledge either by withdrawal of support or the institutional substitution of one by the other. In reality, science teachers struggled with local cultural frameworks and knowledge forms, produced translations of modern science textbooks and created new lexicons, thereby rendering the unfamiliar in the language of familiarity (Venkateswaran 2002). Some of the most interesting encounters between the so-called traditional sciences of India and modern science date back to the end of the eighteenth century and were guided by an optic that subscribed to the idea that modern science could be grafted onto a Sanskritic base (Visvanathan 1985). But by the middle decades of the nineteenth century, with a change of political climate, the epistemic gaze had changed inasmuch as the traditional was viewed as knowledge that had been phased out by the triumphalist

[1] See (Shapin 1983; Prakash 1999; Raina and Habib 2004).
[2] See (Raina 2003, chap. 3).

rise of modern science. Nevertheless, until the beginning of the last quarter of the nineteenth century in some of the sciences and in mathematics interesting pedagogic episodes of naturalization can be encountered—encounters that certainly enrich the literature on science teaching in global multicultural contexts (Sehgal et al. 2000).

In the nineteenth century these experiments and dialogues did not find an echo in the metropolises of science. This possibly arose from the totalizing nature of the discourse of science of the times, wherein it was still difficult to countenance the possibility that science could be done another way. A colleague and I worked on a nineteenth-century Indian mathematician Y. Ramchandra from New Delhi who had developed an alternate way of solving problems of elementary calculus. The British mathematician, Augustus De Morgan, knew of the work and sought to promote Ramchandra's book in English schools. His introduction to the English edition of Ramchandra's book stands out as a testimony to the inherent difficulty of the time to suggest the idea that an Indian mathematician had discovered an alternate pedagogic device to introduce modern calculus to Indians without reference to any topology (Raina and Habib 2004). The project was itself inspired by the Orientalist understanding of the time that Indians lacking in a geometrical understanding had nevertheless to be introduced to modern calculus. De Morgan felt that Ramchandra's book entitled *A Treatise on Problems of Maxima and Minima* (1859) could be employed to instruct English students on how to solve problems of geometry by employing algebraic methods. The book's importance to De Morgan derives from his involvement in the reform of mathematics education in England. However, the project was aborted in India as subsequent educational policy did not encourage projects that sought to structure education around conversations between Sanskritic or Indo-Persian learning traditions.[3] But an equally relevant feature of the late nineteenth century and certainly of the early half of the twentieth century was that the idea of methodological pluralism in the sciences was difficult if not impossible to entertain. This more than anything else may have posed obstacles to the positive reception of Ramchandra's work.

In other words, the response of the South Asian literati to the spread of modern science was more nuanced than one distributed bi-modally between states of acceptance and resistance. Imperial historiography frequently portrayed the early nineteenth-century Indian intelligentsia as decadent and inward looking. On the contrary post-colonial studies have underlined that the growth and communication of knowledge in the Indian public sphere of the 1840s was not impeded by the hidebound structures and rules of a "traditional society." In other words the intelligentsia had begun adapting their practices to the modernist idiom and literary technologies. This process of adaptation was itself a product of decades of reflection on the status of Indian and Western learning (Bayly 1997, 247). During the first decades of colonial rule the state did not have any singular policy on the question of science or the language of instruction. But the priorities of

[3]See also the discussion in about calculus teaching in Brazil discussed in chapter 18.

scientific research were set in relation to the demands of the colonial state and were additionally tethered to the priorities of metropolitan science. At the level of school education, and in particular after 1835, Western science was expected to promote Christian values.[4] Four decades later evangelicals and missionaries discovered that the project had failed miserably, since their Indian students had taken to Western science without taking to Christian religion or values. Within the community of colonial officials, competition among amateurs stimulated scientific research. The discriminatory relationships between colonial officials and their colonized subjects characterized by the sheer asymmetry inherent in the colonial experience prompted a positive evaluation of the Indian scientific traditions by Indians themselves (Bayly 1997, 253). By the middle of the nineteenth century heterogeneous networks of research and teaching emerged in the South Asian region. These networks played a significant role in the localization of modern science and in the enrollment of networks of local knowledge producers into the embrace of global science. One specific channel for the universalization of material and cultural practices is evident in the calibration of scientific instruments and the standardization of scientific practices as these instruments and practices traveled to venues outside Europe (Raj 2007).

Similarly, in the domain of technology a recent study by Geijerstam entitled *Landscapes of Technology Transfer* chronicles the visit of three Swedish engineers, Julius Ramsay, Nils Mitander and Gustaf Wittenström, to India during the years 1860–1864 to establish iron producing plants in the Kumaon region and in Burwai in the Narmada valley. The history of the ironworks established by these Swedish engineers reveals the differences between iron production in India and in Sweden. The establishment of an industrial enterprise of the scale of the Kumaon and Burwai works was preceded by mineral surveys undertaken by British explorers who for their mapping of natural resources depended on local traditions and local knowledge; this local knowledge was gradually assimilated and integrated into the practices of Swedish and English engineers. In like manner, existing knowledge of traditional iron making, Geigerstam documents, proved indispensable for British surveyors. Nevertheless, the relationship between the local informants and the recipients was never free of conflict and involved the clash of differently perceived interests. From the perspective of the colonizers and industrialists, the ties between science and commercial or industrial interests were fairly close and closely guarded. The fascinating feature of this reconstruction is that the absence of archival material is supplemented by field studies that fill the gaps in our knowledge of the two works; the planning was fairly complicated and yet the different natural resources of the two regions meant that the plants were powered very differently (Geijerstam 2004). Furthermore, from the perspective of the history of technology, the Swedish engineers in India benefited from international networks of the iron-making trades and knowledge moved fairly rapidly across continents despite what appears by contemporary standards to be fairly sluggish modes of

[4] See (Gosling 1976; Habib and Raina 1989; Venkateswaran 2002).

communication. The technology that arrived at Kumaon and Burwai was the most modern and the inability to realize a successful innovation could have had little to do with its obsolescence. In fact the socio-technical system that had been elaborated at the iron works was fairly brittle since the boundaries between the British management, the Swedish engineers, the British skilled workmen and the Indian workmen were rendered vulnerable by the conflict ridden nature of the relationship between the different groups of actors. The system was further compromised by the continuous addition of elements by the colonial system that weakened it even more. These among a complex assemblage of economic and technical factors ensured that the two iron works were never able to integrate into a stable network of social and economic interests that might have ensured their sustenance (Geijerstam 2004). This “thick” photographic and literary contextualization of a technological system ably navigates between the complex issues involved in the process of the transfer of technology.

15.3 The Modernity of Science and the Nation

The institutional and organizational context within which modern science was domesticated is equally important. Most histories of science recognize three organizational phases of this process of the institutionalization of modern science (Visvanathan 1985). The first is considered the period of the great surveys commencing in the late eighteenth and early nineteenth centuries when the East India Company initiated enormous projects to map the terrain, resources and the peoples of the South-Asian subcontinent, such as the Geological Survey of India and the Trigonometrical Survey of India. The second phase corresponds to the founding of learned societies, such as the Asiatic Society of Bengal and, in the second half of the nineteenth century, the Indian Association for the Cultivation of Sciences, a voluntarist society founded by the first generation of modern Indian scientists, the National Institute of Sciences—known today as the Indian National Science Academy—and dozens of others founded in the twentieth century. The third and most intense phase was the establishment of a scientific research system within the universities (Raina and Jain 1997).

One of the most important decisions taken after the annexation of India by the British imperial crown in 1857 was the founding of the universities in Mumbai (Bombay), Chennai (Madras) and Kolkata (Calcutta), (Ashby 1966). The universities or “first generation” universities established in India were modeled after London University. These were largely examining bodies rather than teaching universities or teaching and research universities. The modern university was visualized as the colonial government’s primary organization for the production of an Indian class to enable the governance and administration of the empire (Kumar 1991). The universities primarily focused on literary and humanistic studies (Viswanathan 1989). Within less than a decade of the founding of the universities there was a growing demand for the introduction of science education within the charter of the university. The absence of science education in the universities was supplemented by the founding of scientific societies such as the Indian Association for the Cultivation of Science mentioned above.

A “second generation” of universities came to be established in the early decades of the twentieth century. Established through voluntarist donations, they were modeled on Oxbridge and were equally inspired by the globalizing idea of the Humboldtian University. The latter centered the university as the primary site for the production of scientific knowledge. By the time India became independent of colonial rule reasonable centers of scientific research had emerged, not just in the Presidency towns of Bombay, Calcutta, Lahore and Madras, but also in Bangalore, Benares, Delhi, Hyderabad, Pune and Jaipur, to name a few. These universities developed fledgling research facilities outside the imperial research institutes established under colonial rule. This was an outcome of decades of struggle pressing for the introduction of post-graduate teaching and research. In 1904 the University Charter Act was finally passed that more or less announced the commencement of research in the Indian universities. Prior to this development, research was either pursued in imperial institutions mentioned above or by Indians working within voluntarist learned scientific societies (Raina and Jain 1997). It has been remarked that British recognition of Indian independence really came in 1914 when Indian scientists organized the first Indian Science Congress (Dionne and Macleod 1979).

During the period 1850–1880, at the level of higher technical education, the designs of the colonial capitalist state were manifest in the establishment of technical schools and colleges explicitly oriented toward producing a class of technical personnel trained in public works of engineering essential for the sustenance and reproduction of colonial rule. The changing place of Britain in the international economy required that the colonial state be innovative in the founding of formal technical institutions (Inkster 1991).

Clearly then classical percolation models have proved unsatisfactory in comprehending the relationship between modern science and culture in colonial India. The expansion of European sciences was catalyzed by the joint efforts of several actors with divergent motives and included imperial bureaucrats, their scientific entourage, businessmen, missionaries, and on the other side indigenous elites and the literati who finally had to legitimate the uptake of this new knowledge form. Indigenous elites visualized this encounter with science as a means for enriching their repertoire of skills as well as a path to revitalization (Kopf 1969; Panikkar 2007). Studies of Ayurvedic and Unani and Tibb medicine in late nineteenth-century Delhi suggest that traditional knowledge was often reworked and configured in the light of modern scientific developments (Metcalf 1986; Panikkar 1992).

The transformation of Ayurvedic and Unani Tibb medical practice in the late nineteenth and early twentieth centuries was initiated through the efforts by three iconic figures: P.S. Varier, Hakim Ajmal Khan and P.C. Ray. The latter two were closely associated with the nationalist struggle. The trope of decline of the traditional systems of medicine was employed by the three of them to press for the modernization/revitalization of traditional systems of medicine. Revitalization in their eyes required three transformations: an epistemological reframing of these systems of medicine, a reform of institutional practices of Ayurveda and Unani, and a radical reorganization of the manufacturing and distribution system of drugs and medicaments (Raina and Habib 2005). All three components of the revitalization of the traditional system of medicine were to be informed by the practices of modern science and were adapted within the frame of the existing medical systems. Inasmuch as the colonial system was also one of economic expropriation, the manufacturing and distribution of Ayurvedic and Unani pharmacopeia aligned with the early twentieth-century politics of self-rule. The Indian nationalist movement, unlike the contemporary incarnation of ultra-Hindu nationalism, was one premised on a theory that sought not merely to liberate India of the yoke of colonial rule but to liberate the English of the idea of imperialism (Visvanathan 1997). In order to do so, new identities were often forged—and this is reflected in the creation of institutions such as the Ayurvedic and Unani Medical College (Raina and Habib 2005). This process of reworking skills of traditional knowledge practitioners within the frame of contemporary scientific practices was institutionalized within educational organizations set up for the process and was reflected in the pedagogy of institutions such as the Kala Bhawan, Baroda or the college of Unani Tibb in Delhi (Raina and Habib 2004). This dynamic relationship itself constantly reshaped modern science.

On the other hand, within the traditional historiography modern science is seen as the vector of a modern worldview. As a central element in the social theory of modernization, modern science encroaches upon and invades the domain of the traditional sciences of non-Western societies. The slow expansion of modern sciences is seen to be an outcome of impediments and resistance posed by persisting pre-modern forces within these societies in transition. This explanatory frame finds its most explicit elaboration in the colonial science model of Basalla (1967), much disputed on several counts and from a number of perspectives.[5] The model suggested that what the West took from the East was raw information that was cooked, processed, theorized upon, and subsequently transferred back to the East. Premised on a Rostowian understanding of the transfer of technology, it combined descriptive and prescriptive components of theorizing. The practice of science mirrored the dependency of the colonies on the metropolises of science in the West, in terms of problems considered suitable for research as well as in terms of theoretical influences.

The central question concerning the slow expansion and institutionalization of science under colonial rule, especially during a period of extended, expansive and creative contact between European scientists and Indian savants, remains an important one. This was quite in contrast with the situation in Japan after the Meiji restoration in 1867. One plausible explanation for this tardy growth

[5]See (Macleod 1982; Baber 1996; Raina and Habib 2004).

had to do with the priority accorded to the field sciences over the pure sciences (Sen 1988). But the fact remains that India was a colony and sovereign nations like Japan and China could negotiate their trajectories of institutionalization and scientific modernization more effectively.

The study of the complex social processes involved in the institutionalization of Western/modern science in India has recently been marked by the decline of diffusionist models of the history of science which in turn was triggered by the interrogation of the underlying theory of modernization (Baber 1996) and the recognition that these models trivialized contributions of local knowledge (Storey 1996). Nevertheless, it was important to ask what the impact of colonial rule was on indigenous scientific knowledge and institutions, and what roles did British and Indian scientists play in the creation of scientific knowledge and the institutions of science. The symbiotic relationship is evidenced in the construction of a large-scale scientific research system and the emergence of the colonial capitalist state. The colonial state was innovative in founding formal technical institutions that later served as models "for replication in England in the late nineteenth century and the colonial encounter contributed to the development of technical education in England" (Dionne and Macleod 1979). Furthermore, the "histories of colonialism" are also implicated in the disciplinary history of the "universal sciences"[6] as much as the state played a role "in the development of the scientific analyses of society" (Kalpagam 2000, 38). The imperatives of governmentality accordingly produced statistical knowledge of the country, which included classificatory schemes for the census. While newspapers were instrumental in creating public spheres, new conceptions of the economy and society crystallized in new discourses of history and progress (Kalpagam 2000, 52).

Different meta-historical frames sought to get a handle on the differences evident in the geography of knowledge. The center-periphery framework tried to approach the fundamental asymmetry characterizing the conceptualization of the process of the production of knowledge (Ben-David 1984). Analytical categories such as that of colonial science portrayed the knowledge produced at the periphery as being derivative in nature, and therefore as a lower order of science: from the end of the eighteenth century processes of data gathering and calculation in science were considered to be lower order activities in the Western European scientific imagination (Daston 1994). Consequently, the science pursued in the colonies was of an empirical nature; the task of theoretical synthesis was to be performed in the metropoles of London, Paris, Berlin and so forth. (Pyenson 1985). The science pursued in Calcutta, Auckland, Beijing or Tokyo in the early twentieth century was never quite the real thing. But the advantage of a scientific research career far from the metropolis was the absence of peer pressure, and this created the possibility of idea hybridization at the periphery (Chayut 1994). This is instantiated in the case of S.N. Bose from Calcutta collaborating with

[6]See (Nandy 1980; Visvanathan 1985; Nandy 1988; Baber 1996; Kalpagam 2000, 38; Raina and Habib 2004).

Einstein in the formulation of quantum statistics in the 1920s, and of M.N. Saha, also in Calcutta, developing the incipient program of theoretical astrophysics and astronomy through his work on the ionization formula. Similar idea hybridizations could account for C.V. Raman's contribution to the phenomenon of scattering, Heidekei Yukawa's development of meson theory, and Tomanaga's contribution to the study of quantum electrodynamics. The possibility of science at the periphery surpassing science at the center, DeVorkin suggests, arose in Saha's case from his "relative freedom in isolation" that enabled him to tread entirely new pathways, although it constrained him from exploiting the potential of his theory (DeVorkin 1994, 126).

Other metahistories focusing upon scientific practices ran against the grain of these earlier explanations (Pingree 1992). These metahistories appeared during the 1980s, but during the initial stages of decolonization, scientists in India produced a history of science that sought to break out of the frame of a Eurocentric history of science, seeking cognitive justice (Visvanathan 1999) and a due place in the sun (Bose et al. 1971). Inspired by the Needhamian historical project, some of them attempted to identify the causes behind the tardy expansion of the sciences in India over the last two centuries (Rahman 1984; Sen 1988). Colonial policies obstructed the path of authentic modernization: this was further manifest in explicit colonial reservations concerning the abilities of Indians to pursue science. The expansion of science was arrested by colonial interests, and sometimes explicitly racist policies (Kumar 1991).

However, until the end of the nineteenth century, episodes of the encounter between the traditional sciences and ways of knowing and that of modern science continued to play themselves out on the growing stage of modern science in India. An anthropological engagement with these episodes reveals a great deal about the localization of modern science and re-opens the question of science and modernity. Indian scientists schooled in modern science struggled to inaugurate a scientific and technological research system. The purported objective was to draw India closer to the international community of science. This first generation of Indian scientists embarked on an unenviable project of building bridges between the science they were pursuing and the knowledge forms that were part of the cultural life of the region before colonialism (Raina 2003). This task often produced a variety of responses that appeared curious to the Western eye. For example, Jagadis Chandra Bose, the first of modern India's physicists, is one of the deities in the pantheon of the founders of the modern scientific tradition in India. Amongst Indians, Bose's research has been seen as India's response to Western science, while in the West he continues to be an enigma. But scientists in the West and in India have often marveled at his acumen as an inventor of instruments. His name, alongside that of Marconi, is often associated with a misplaced priority dispute concerning the discovery of radio waves (Dasgupta 1999). From a contemporary perspective, Bose is credited with the production of short wavelength radio waves, and was the inventor of truly ingenuous coherers. It has been suggested by some that

Bose's later work on plant physiology, alongside Ramanujan's equally enigmatic mathematical style, could be seen in epistemic terms as an attempt to construct an alternative Indian science (Nandy 1980).

From a metatheoretical perspective attempts to explore the "cultural context of scientific creativity in science in the non-Western world" was itself a product of disenchantment with modern science. In other words, the inevitability of modern science was no longer considered tenable and it was increasingly felt that there were other trajectories available—trajectories that were labeled "alternate sciences": possible sciences eliminated by the march of a dualist modern science. Traces of these alternate sciences could be found, it was argued, in those precolonial forms of knowledge, including scientific knowledge whose evolutionary trajectories did not intersect with those of modern science. And those whose trajectories did intersect with modern science during the course of localization or domestication were eventually marginalized. This search recognized that the search for an Indian alternative would be "impossibly unmanageable" (Nandy 1980, 15).

The assimilation of modern science naturally commences at the level of pedagogy. This process was normally conceived in terms of the replacement of the traditional pedagogy and curricula by the new ones under the pressure of the imperial dispensation. In reality, science teachers had to contend with local cultural conceptions and knowledge forms, as well as the need to mobilize existing teachers within modern schools. These contingent pressures provided avenues for the localization of "universal science," and as some recent studies have suggested, provided pedagogic exemplars that in turn influenced the education system in England (Baber 1996; Tschurenev 2008).

15.4 Science in Development and Decolonization

The scientific research system was not established afresh in independent India but built upon structures established during the period of colonial rule, tailoring them to a new social and political agenda. Before independence, although there were just a few universities in the country, seen in the context of that time, they were the primary sites for the production of quality scientific research. Over the last fifty years, a number of factors coalesced to move scientific research away from the universities to what may be termed elite research institutes (Raina and Jain 1997). This shift began initially very slowly in the 1950s, even though the founding fathers of science in modern India were aware of the long-term dangers of such a development. The founding fathers were sensitive of the role of the university in the building of a scientific research tradition, but were compelled to carve out their own research institutes outside the university system. The evolution of the Tata Institute of Fundamental Research, Mumbai, the Indian Institute of Science, Bangalore, the Institutes of Technology and then, from the 1970s onwards, the mushrooming of institutes funded by the Department of Science and Technology and the Atomic Energy Commission appeared to have sealed the fate of research in the universities, though a handful of universities bravely rallied around and managed to keep quality research going. This shift was catalyzed by a number of domestic structural changes in the world of higher education as well as global changes in the regimes and practices of science.

From the beginning of the twentieth century the leadership of the scientific community in India was closely associated with the nationalist struggle, and legitimated science by highlighting its importance in nation building and development. In the post-independence period, science was strongly coupled with the process of decolonization as well as the programs of the developmental state (Zachariah 2005). In a planned economy, the priorities of scientific research were integrated into policies of the 1950s, relating to matters such as import substitution and the building of indigenous capabilities. Promoting economic self-reliance, in turn, was anchored on scientific and technological self-reliance (Abrol 1995). In order to accomplish these ends, it was necessary for the scientific community to enlist the political establishment in the realization of its avowed goals and objectives. This was successfully accomplished under the leadership of Nehru. The generation of Indian scientists who assumed leadership of the scientific community at the time of independence—Homi Bhabha, S.S. Bhatnagar and Meghnad Saha—while acknowledging the contributions of the previous generation rushed on to complete the processes of professionalization and institutionalization that had commenced (Raina and Habib 2008). They were pressurized into leap-frogging, as they feared the nation might lapse once more into the state of dependency or neo-colonialism. This anxiety manifested itself in the form of several imperatives. The industrial research imperative provided a fillip to the Council of Scientific and Industrial Research that blossomed in the 1950s. Between the 1950s and 1960s, over twenty CSIR institutes were set up, a feat that has never been repeated since (Raina and Jain 1997). Similarly, the nuclear research imperative set up the axis for the growth of nuclear science. By the 1970s, while science had undoubtedly expanded, it had done so at the expense of the universities in India. Mission-oriented research transformed in significant ways the ethics of research both in India and abroad. It is important to remember, however, that this was then a global trend and not just true of India.

Once scientific research acquired a home outside the university and established itself in the research institutes driven by goals other than the pursuit of knowledge, it often abandoned what Shiv Visvanathan has called, its “incest taboos” (Visvanathan 1997). In the Indian context, we can see over the last fifty years the socialization of generations of science and engineering students in a technocratic ideology of science. In fact, with some notable exceptions, this is the only ideology of science that seems to captivate entire generations of Indian students and gives science both its power and a legitimacy that was not questioned until the 1980s. Further, the Manhattan project irreversibly transformed another very fundamental norm of scientific leadership. Leadership in the scientific community before the 1950s, according to a number of sociologists, had hitherto been intellectual or paradigmatic. Important contributions to science were rewarded by a social system that conferred awards, memberships of societies and leadership to scientists who had made contributions to the domain of science. Afterwards, the Manhattan project leadership became institutional and institutions became territories. This transformed the norm for scientific leadership into an ability for garnering and managing scientific teams. Under certain circumstances institutional leadership prevailed upon paradigmatic or intellectual leadership (Gibbons and Wittrock 1985).

These transformations were debated in the scientific community both in India and abroad. The seminal contributions of the first generation of scientists during the pre- and post-independence period had integrated them into the global community of science and collegial ties enabled them to forge collaborative networks of research as well as of policy with their colleagues in Europe (Anderson 1999a,b). Scientists from Britain and France such as J.D. Bernal, Frederic Joliot-Curie, P.M.S. Blackett and J.B.S. Haldane played an important role in cementing these ties which proved beneficial for the organizational expansion of Indian science. The scientists mentioned had a left wing orientation and were keen on bridging the gap between the developing and the developed world, especially in their insistence that science belonged to the global commons (Petitjean 1999). UNESCO on the other hand contributed to the organizational development of science in the former colonies. And as the Cold War progressed it possibly became the only international agency that was able to keep channels of scientific communication open between both sides of the Iron Curtain. Naturally, India benefited from such international collaborations. The collaborative ties of the disciplinary community often prevailed over that of the nation (Raina and Habib 2008). Yet, in the extra scientific sphere, scientists abroad could hold contrary, patronizing and, sometimes, imperialist positions. By the 1970s, India had come to serve as a role model for several of the nations that had undergone decolonization since the 1950s. In other words, if in the pre-independence period the processes of localization involved the reorientation of traditional cognitive orders along the lines of modern science, in the post-independent period the processes of localization were more of an institutional and organizational nature than one of reinventing the cognitive order of science.

The 1950s and 1960s were the high tide of the Nehruvian era of science, of heavy industry, big dams, and the period when nuclear capabilities were developed. However, this was also a time when a larger number of Indian students began to undertake their higher studies in the United States which had by then emerged as the new scientific destination with an excellent university system. India's elite technological institutes, established through collaborations with the United Kingdom, Germany, USSR and the USA, developed their curricula on the lines of the American university system—from the outset they adopted MIT and the California Institute of Technology as their models (Sebaly 1972). In the subsequent decades, while there was a spillover of students from the Indian Institutes of Technology

(IITs) into Indian industry and the research system, there was also a serious brain drain into the American university system. A minuscule number of students returned to India after completing their higher studies and manned the departments of the IITs and other research institutes (Sukhatme 1994).

By the beginning of the 1970s, the image of science the world over had reached a critical turning point, almost as momentous as the one India reached in the 1950s. Close to three decades of the optimism that characterized science as the endless frontier began to fade (Elzinga and Jamison 1986). Skepticism concerning strategies and programs of development in the Third World, and large-scale investments in mega-development projects, accompanied by the realization amongst economists of the failure of trickle down to deliver on that much-hyped conception of development began to come unstuck, even in policy circles (Raina 2003). The world suffered through an oil crisis and the idea that nature was not an infinite resource of recyclable goods began to ring the alarm bells in the world of science. The consequent emergence of the idea that small is beautiful initiated a process of rethinking the agenda for science both in India and abroad. These developments were compounded by the rising tide of anti-modernism, and anti-science and anti-vivisectionist movements. Clearly, a particular kind of scientism had run its course. This disenchantment produced in India a diversity of intellectual responses. At one level, it seeded an interrogation of European modernity and its conjugate modern science as solely paradigmatic of modernity and science (Nandy 1988). This was accomplished from two vantage points among others. The common understanding shared by both was that the dualism of fact and value logically culminated in a vivisectionist science that confronted its limits and its possible culmination in the concentration camps of Auschwitz and the nuclear destruction of Hiroshima. This modernity took its toll in genocidal development that the third world had been witness to as well (Uberoi 2002). In the realm of the sciences, this inspired the search for alternate sciences and the possible episteme that underpins them within the scientific culture of modern India.

In conclusion, it could be said that decolonization involved firstly the reconfiguration of the institutional context of colonial science to serve the politico-economic policies and programs of the new nation state. The task was not conceived as one requiring the demolition of British legacies, but of pragmatically assimilating elements that were suited to the post-colonial developmental goals. Secondly, movements for independence from colonial rule had planned for the establishment of educational and scientific infrastructure after the passing of colonialism. The scientific leadership, earlier involved in the anti-colonial struggle, acquired latitude for negotiation and influence with the post-independence political leadership in fashioning the destinies of the scientific and technological institutions of independent India. The relationship between a statesman such as Nehru and the scientific leadership represented by scientists such as Bhabha has become emblematic of this phase of science in decolonization. The political legitimacy conferred by the state on science and vice versa facilitated the building of scientific institutions. Strategic areas of scientific research were protected from bureaucratic and political intervention; this created the illusion of the autonomy of science from the social institutions that legitimated it. The dualist character of the economies of the region further reified this chimera of autonomy. Nevertheless, by the end of the twentieth century researchers at premier institutes of scientific research had joined the global scientific community with intellectual ties extending over long distances (Schott 1998). Despite the relative evening out resulting from the development of new communication technologies, certain features of science as practiced under colonialism remained. As happened with the case of Saha and the inauguration of theoretical astrophysics, research programs pioneered in India were not able to sustain the momentum generated at the moment of creation. A study of a research program pursued at the Department of Aerospace Engineering at the Indian Institute of Science, Bangalore, reveals the difficulties of stabilizing research networks at the periphery. The point is further reinforced by scientometric studies suggesting that collaborative ties between institutes in India and the West are much stronger than the collaborative ties between institutes in India itself. Consequently, long-distance ties between scientists have grown much faster than ties between scientists in India or ties between scientists in neighboring countries (Schott 1998).

The expansion of "Western science" and the globalization of science itself do not reveal the replication and reproduction of a paradigmatic version of science that emerged in Northern Europe in the seventeenth and eighteenth centuries. Sociology of scientific knowledge and theories of multiple modernities have divulged the untenability of a canonical version of Western science or modernity migrating unattenuated across impermeable boundaries and is installed in the non-West. The complex process characterizing the encounter between modern science and other knowledge forms results in the emergence of local versions of modern science. In the process, the encounter metamorphoses modern science. These local variations manifest themselves in the diverse organization of pedagogical and evidential cultures. Under the microscope the purely normative account of science, or its globalization, begins to exhibit distinct regional adaptations, rather than homogenization on the Western model.

The globalization of Western science, or to use a more neutral term, modern science is then not a process that commences from an original home of modern science (Needham 1969). In evolutionary terms we have several sciences in a constant relation of localization and globalization. As Needham's river metaphor so aptly suggests, modern science emerged in a specific historical context of Western Europe and on expanding into other cultures it undergoes a dual process of universalization and localization. Does abandoning the idea of the universality of science in an "absolute, or even functional, sense" lead us into the trap of localism? Montgomery argues that the recognition of the context of knowledge is not identical with reducing the one to the other. The history of scientific transmissions has often been preoccupied with the percolation and diffusion of a pre-existing version of universal science. The multicultural history of science appears to suggest that universality is not given a priori but is constantly refurbished and thus evolves over time. This occurs within the context of the encounter of local scientific knowledge with so-called global science. In either case, the time is ripe enough to rethink the narratology adopted to study this process of domestication and globalization. Only an acute sensitivity to the context of the circulation of knowledge would ensure that the new histories would not lapse back into the older narrative forms.

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PART 3: The Place of Local Knowledge in the Global Community

Chapter 16
Survey: The Place of Local Knowledge in the Global Community

Jürgen Renn

16.1 Local Knowledge in the Niches of a Globalized World

Local knowledge is a relational concept, to be defined only with regard to a particular historical situation as well as to its genesis and future development. It describes those social competencies in solving problems and anticipating their solutions that are not part of a globally dominant constellation, but rather are associated with a geographically or socially limited spread. Local knowledge in this sense may have been once part of globalized knowledge or harbored the potential to become so in the future, "local" not necessarily being an intrinsic quality of the knowledge. Local knowledge may evolve into less local or even global forms diachronically, that is, by becoming part of a tradition connecting spaces that temporarily relate to each other, and synchronically, that is, by becoming part of an exchange connecting different spaces simultaneously contributing to this evolution of knowledge. Like globality, locality itself is not a given, but is rather the result of historical processes. Local knowledge emerges from or is pushed into the niches of a world which, in all historical situations, is more or less connected and determines these niches as those spaces that are for the time being not part of the connectivity.[1]

Local knowledge connected with traditional techniques for mastering primary living conditions, such as food production, medicine, architecture and mobility, may seem, due to economic globalization processes, to be generally on the retreat, confronted as it is with the economic and technological powers of global capitalism. On closer inspection, however, it has turned out that this global capitalism has itself, in the course of its emergence, critically benefited from the local knowledge that it now appears to repress. As Marshall Sahlins states:

> Rather than a planetary physics this is a *history* of world capitalism—which, moreover, in a double fashion will testify to the authenticity of other modes of existence. First by the fact that modern global order has been decisively shaped by the so-called peripheral peoples,

[1] Local knowledge in the sense used here may also be designated as situated knowledge in the sense of Susanne Rudolph (2005, 12), emphasizing the close relation between knowledge and practice.

> by these diverse ways they have culturally articulated what was happening to them. Second, and despite the terrible losses that have been suffered, the diversity is not dead. It persists in the wake of Western domination (Sahlins 2000, 418).

In times of colonialism, "local" knowledge of medicine had in fact become part of a global communication system.[2] Later, in the period of imperialism, such autochthonous medical knowledge was increasingly marginalized by supposedly superior knowledge about tropical diseases, for instance, which also served to legitimize European domination (Haynes 2001). However today, local knowledge is anything but obsolete in view of its role both for survival in the niches of globalization and for its potential to offer globally relevant and alternative solutions. Before exploring this potential further, let us take a brief look at how local knowledge was pushed into these niches and then consider in more detail one example which may clarify the nature of local knowledge as well as its developmental potential. A short survey of the international situation around 1900 may help to assess the global power constellations largely determining the relation of local and global knowledge systems.

By the beginning of the twentieth century, the presence of Western military power, capital, products, science, technology and ideologies could be felt in virtually every part of the world.[3] In Europe and North America, strong industrial and commercial centers had evolved which formed the basis for dominating the more southern and eastern parts of the world, either directly through political and military control or indirectly through political, commercial and cultural influence.

In Latin America, post-colonial nation states had emerged from struggles for independence since the beginning of the nineteenth century. Their economy remained characterized by the export of primary resources and agrarian products and was dominated by foreign commercial powers, such as Great Britain and the United States. Elites with European roots and globalized urban life styles coexisted with indigenous societies more or less affected by processes of globalization. The history of Latin America in the late nineteenth and early twentieth centuries was shaped by Western models of industrialization and modernization, a strong dependency on the global economy and conflictual political attempts to deal with the consequences of this dependency, often leading to authoritarian rule.[4] This constellation has been conceptualized by dependency theory which explains first the relationship between the newly independent states in Latin America and the leading economic nations and second the role of elites within those states (Cardoso 1977).

[2] This is shown by Sabine Anagnostou (2000). Similarly, Nicholas Thomas (1991) describes Polynesian-English trade relations and economic entanglement in eighteenth and nineteenth centuries not only as an indicator of an entrance of autochthonous people into the Western capitalist system, but as a mutual exchange of knowledge.

[3] For the following, see (Osterhammel 2009) and also (Anders and Münter-Elfner 1999; Steger 2003).

[4] See, for example, (Halperín Donghi 1985).

Since the late nineteenth century, most of Africa has been divided into colonies of European powers by artificially drawn boundaries. Local economies and societies were destroyed or reshaped according to European priorities in global political and economic competition, focusing almost exclusively on the exploitation of primary resources.[5] A major event at which such far-ranging decisions were taken is the Berlin Congo Conference of 1884–85. The redrawing of boundaries and domains of political influence eventually led to the emergence of new social and political constituencies. Investments in infrastructure did contribute to the spread of goods, technology and knowledge. But they were directed primarily by the interests of the colonial powers rather than by the aim to improve the living conditions of the local population in terms of education, water management or public health. The strategy to consolidate western domination by investments in infrastructure emerged around 1900, but was massively implemented only after World War II when the necessary economic resources were available and when the struggle for independence provided the urgency and motivation.[6]

Also, large parts of Asia were under European control. India belonged to the British Empire, whereas Southeast Asia was, for the most part, under the domination of other Western powers, such as France, the Netherlands and the United States. The United States became a colonial power on the Philippines and the Mariana Islands after the Spanish-American War in 1898. In India, the British Empire established a society parallel to and above the indigenous ones in order to enlist, educate and corrupt local elites for the purpose of colonial control.[7] China retained its dynastic rule but became the pawn of European interests (Petersson 2000), while Japan—not least deterred by the Chinese example—made successful efforts to maintain its independence and to become a colonial power in its own right (Conrad 2005). In fact, Japan entered the realm of global economic and political competition more or less on its own terms by appropriating Western means and methods of gaining and exerting power, such as military technology, industrialization and science (Beasley 2001, chap. 9). In the process, Japanese society kept its non-Western identity yet allowed for globalized scientific and technological knowledge to replace local traditions (Inkster 2001). A striking example for the dialectics of takeovers of foreign knowledge and its appropriation is the way in which Japanese national history was constituted on the model of German national history with the aim to substantiate Japanese claims of autochthony (Conrad 2004, 2007). In China, the last dynasty eventually crumbled under the combined pressures of European interventions and internal instability, eventually making way for a fragile and superficial republican order that imitated Western models; this was quickly taken apart by struggling warlords (Waldron 1991; McCord 1993).

[5]See (Oliver and Fage 1962, 172–174). Frederick Cooper (2005, 182–83) gives economic reasons for colonial expansion in the context of rivalry between different European empires which were the motivation for expansion and exploitation.

[6]For infrastructure as an instrument of consolidation of imperial power, see (van Laak 2004).

[7]See, for example, (Metcalf and Metcalf 2002).

In Australia, then part of the British Empire, the indigenous population was marginalized by white settlers (Rowse 1999, 635). Most of the indigenous population of the Pacific islands was exterminated during the nineteenth century by imported diseases such as measles and influenza, but also due to imported weapons that changed the character of local conflicts into deadly wars. Other parts of the population were either killed or enslaved by Western colonizers (Bushnell 1993; McNeill 1994).

The gradually emerging global infrastructure of transport, commerce, communication and administrative control had, however, not yet penetrated the interior of all countries and continents, some of which were thus affected only peripherally by the economic and political globalization processes in the sequel of colonization and industrialization. Remarkably, this gradual and sometimes halting diffusion of global infrastructure was not just characteristic for pheripheral areas of colonization, such as the interiors of Amazonia or Sub-saharan Africa, but also for areas in the focus of colonial efforts, in particular, North America, thus constituting the emphatic notion of "frontier" (Waechter 1996). Alongside brutal suppression in the colonized territories, the destruction of non-European societies and the exploitation of their people and resources, some societies, for instance in New Guinea or Micronesia, were able to subsist using traditional economic practices and local knowledge essentially transmitted unchanged over centuries.

Over the course of history, many types of local knowledge have evolved and disappeared. Local knowledge is embedded in specific social and natural contexts, which often serve both as its object and as a medium of its expression, such as when spatial knowledge is encoded by landmarks. Accordingly, when such contexts change due to migration, for example, or when habitats are destroyed or new technologies open up new ways to solve "traditional" problems, for instance regarding mobility, local knowledge is easily lost. Local knowledge is part of traditions that are invented and that vanish under specific historical circumstances (Hobsbawm 1983). Many kinds of local knowledge have thus been lost in human history. One of the greatest losses worldwide was due to European colonization and its consequences.

16.2 Intrinsic Versus Extrinsic Development of Local Knowledge and the Example of Local Navigation Techniques

Some kinds of local knowledge have been preserved over major historical breaks by simply adapting it to new circumstances, for example, when wire is used instead of liana to build houses according to local traditions, as is the case with indigenous populations in Brazil. Other kinds of local knowledge have further evolved and become part of globalized knowledge, in particular, by being networked with other knowledge and by overcoming its context-dependence in higher-order structures of reflection. This process, which must have also happened to some of the local knowledge at the origin of European expansion, is characteristic of the intrinsic development of a system of knowledge.[8] It is, however, important to emphasize the fact that not only European knowledge was globalizing. Even in colonial situations knowledge and epistemological systems of other provenance became important parts of globalized knowledge.[9]

A telling example are navigational techniques that depend on observing the stars, which must have emerged as local knowledge all over the world.[10] In the course of the development of Western science, this knowledge was eventually able to take into account the different ways in which the stars appear in different parts of the world, thus overcoming its context-dependence. However, such an intrinsic development does not necessarily lead to a system of knowledge that is better able to solve a given local problem. For more than a thousand years, traditional Polynesian and Micronesian navigational techniques have enabled sailors to undertake long-distance trips between islands that would take them several days out of the sight of land (Oliver 1989). In Western imagination and thinking, islands are genuine places where traditional knowledge is preserved from any change. This "isolated" geographical situation of islands gives way to a misconception of island societies as ahistorical and their social subsystems as unchangeable. In consequence, anthropologists and historians who commend the maritime ability of Polynesians often neglect the consequences such skills had for the exchange of goods and knowledge. But even precolonial contact between different islands was able to alter societies and knowledge systems, as is underlined, for example, by Nicholas Thomas (1997). The knowledge underlying these techniques comprises elements that from a Western perspective fall into entirely different domains, such as astronomical, geographical, oceanographical, meteorological and ornithological knowledge.[11] Stars provide the bearing, waves and winds an indication of the speed of the voyage, while birds as well as water currents and the color of the water help to identify the vicinity of land.

Yet, such local knowledge consists of more than a collection of isolated pieces of information compiled according to specific needs, or it could hardly meet the challenges and vicissitudes of long-distance seafaring. Rather, it must have some of the same properties as the corresponding Western scientific and technological knowledge, namely predictive power even when only incomplete information is available, flexibility, coherence and transferability from one generation to the next. It turns out that traditional Micronesian knowledge about navigation has a rather sophisticated cognitive architecture that can be described in terms of men-

[8]An example is the emergence of globalized mathematical knowledge from local accounting techniques in Babylonia by an iteration of representation and reflection. See chapter 6.

[9]This point is stressed as "border thinking" by Walter Mignolo (2000). Mignolo relies largely on the work of Edouard Glissant (1993). Glissant himself underlines the interconnectivity of knowledge, people and cultures in colonial and post-colonial times which he describes as a *creolization* of knowledge. A global situation in which such *creolization* prevails is described as "mondialité" or globality.

[10]See (Gladwin 1970; Hutchins 1983, 1995), see also chapter 19.

[11]See, for example, (Sahlins 1981).

tal models that allow the "calculation," albeit in an analog way, of the course of a boat on a long-distance trip.[12] One such mental model allows, for instance, the progress of a voyage between two islands to be tracked in terms of one or more "reference" islands. Usually these are not actually visible during the trip. But their imagined relative position to the boat is mentally projected onto a horizon that is conceptualized as a straight line representing the entire trip. In this way, whatever happens to the boat on the trip, whether it is delayed or off-course, can be reckoned with in terms of the virtual landmarks along this imaginary horizon. The navigator can thus accomplish mental operations that, within the framework of Western knowledge, would have required complex nautical calculations. Yet, while such local knowledge may have the same efficacy as globalized knowledge, it is bound to a specific context as well as to context-specific social relations. Furthermore, it is typically embedded in comprehensive views of the world at large ("cosmologies"). In the case of Micronesian navigation by the stars, it depends, for instance, on the fact that this navigation takes place close to the equator, where stars (and planets) rise and set along paths more or less perpendicular to the horizon. This makes it possible that, in the course of the night, one star can simply take over the role of another, just "underneath" it, to indicate a given bearing. This peculiar circumstance can evidently also be rediscovered and reactivated, even when more sophisticated traditions of local nautical knowledge have perished. In contrast, these more sophisticated traditions, due to the omnipresence of globalized knowledge, stand little chance of being revived, or even undergo their own intrinsic development toward globalized knowledge.

Local knowledge also may become globalized as a consequence of extrinsic developments. A striking example is the transformation of a culturally specific understanding of accountability and moral responsibilities into a globalized standard of development projects imposed by the more powerful Western partners in such cooperations. The assumption, for instance, that developmental aid directed at improving water supply should establish waterworks as economically viable, independent units and keep them functioning as essentially self-sufficient enterprises, has become part of a globalized standard for such projects.[13] This standard, however, is hardly supported by any intrinsic development of knowledge about water management in diverse social settings that would necessarily entail this conclusion. Rather, the root of this assumption is a local piece of knowledge, emerging from specific experiences in the economy of Western urban societies, but then extrapolated and imposed, in an extrinsic, politically steered process, onto developing countries. Similarly, the knowledge of how to deal with the HIV/AIDS infection spread by international campaigns in developing countries often includes supposedly globalized standards on how to forge appropriate and "healthy" ways of dealing with the disease, standards that are actually modeled on specific West-

[12] For the concept of mental models, see chapter 1, section 1.3.3.
[13] See chapter 21.

ern ideas of autonomously acting, "empowered" individuals.[14] This spread also constitutes a globalization of local knowledge, anchored in non-universal, Western traditions of conceiving the relation between an individual and the society. Now these culture-specific conceptions are imposed on diverse social environments by the extrinsic dynamics of developmental politics, backed by economic and political globalization.

16.3 The Double Function of Local Knowledge

Local knowledge may be of different kinds. It may serve to constitute social identities by providing reflective resources to assess reality and other kinds of knowledge in the sense of second-order knowledge. But it may also primarily serve to solve problems of human survival, such as food production, communication, healing, building and mobility. Even today, some indigenous populations retain an immensely sophisticated knowledge of their local environment, for example, about local plants used as food and medicine, as raw materials for buildings, as weapons, for making clothes, musical instruments and various kinds of tools, or even in the context of ritual practices.[15] As this knowledge is intimately connected to these specific kinds of uses and not cultivated for its own sake, it may rapidly sink into oblivion once these uses have become obsolete. But local knowledge may also serve to constitute and preserve cultural identity. For the most part, the two functions can hardly be separated from each other, as the elementary example of linguistic knowledge may illustrate, serving both purposes of communication and of constituting cultural identity.[16]

Next to language, religion is a key element in shaping local identity, serving to preserve a group's unity. Typically, religion may also constitute a medium in which identity conflicts are reflected and negotiated, as when the Tupinikim people of Brazil simultaneously follow their own native beliefs and worship the "white man's" God, without seeing any contradiction.[17] Local religious beliefs may also comprise elements of knowledge about the natural world, for instance, about plants and animals, about specific places in the landscape or about astronomical phenomena. The extent to which such religious knowledge is also functional in mastering practical challenges varies greatly from culture to culture, for instance spatial orientation, agricultural rhythms or medical treatments. The intrinsic coupling between such functional local knowledge and its integration into religious beliefs is evidently weak and dependent on specific circumstances.

[14]See chapter 22.

[15]For the case of food, see, for example, (Porter 2006), and also (Nützenadel and Trentmann 2008).

[16]For example, post-colonial literature written in India or abroad in Indian diaspora communities serves to constitute a particular Indian or Indian regional identity by conciously deviating from the dominant English literature. See Kumar (2007) and for the general issue of identity formation by literature, also Anderson (1996).

[17]See, also for the following references to Brazil, chapter 23.

Local knowledge is usually shared knowledge communicated in everyday interactions and practice within a specific community and transmitted from generation to generation. It may, however, either serve to enable individuals to accomplish certain tasks, for instance preparing a certain artifact, or it may become operational only when various individuals combine their shared knowledge in collective actions, in agriculture for instance, or when a group activity is required to erect a major building or monument. This collective dimension may be exemplified by the *mutirão* regime of mutual help among the Guarani in Brazil or by the construction of men's houses among the Eipo people in New Guinea.[18]

Beyond the double function of local knowledge for practical and cultural purposes and beyond its characteristic combination of material and social aspects, it may also take the form of a decidedly second-order epistemic framework. Note, however, that there is no fixed boundary between specific first-order knowledge and reflective second-order knowledge, as is often the case for taboos, which at the same time play a practical and an epistemic role.

16.4 First and Second-Order Knowledge and their Representations

Every human society deals with the generation, transmission and application of knowledge and has accordingly also developed meta-knowledge about these processes. This meta-knowledge may not necessarily become expressed in statements about knowledge but may also be implicitly represented by certain social practices, such as communal or hierarchically organized decision processes, the social organization of learning processes, or the ways in which knowledge is encoded in religious activities. In this way, second-order epistemic frameworks are generated and maintained that regulate the power typically coming with knowledge. Among the Guarani of Brazil, for instance, knowledge is concentrated in the hands of the *Pajé*, the tribe's priest, enabling him to serve as a guide, healer, educator, seer and sorcerer. Such second-order epistemic frameworks hence determine, in particular, who possesses which knowledge, and go a long way in determining the collective identity of a society, evidently shaped by the way it conceives of itself and hence also by meta-knowledge.

First-order local knowledge is internally represented by mental models enabling individuals to master intellectual tasks, such as selecting plants, preparing food or path-finding in a context-dependent way.[19] One example is the mental model underlying Micronesian seafaring discussed above. Accordingly, first-order local knowledge is materially represented by elements of the environment, context-dependent actions, as well as the tools and objects employed in such actions. In the conventional sense, it is thus in many cases "tacit knowledge."[20] It may be socially represented by ritualized forms of communication involving elements of

[18] See (Thiering and Schiefenhövel 2012).
[19] See chapter 1, section 1.3.3 and also (Gentner and Stevens 1983).
[20] For the concept of tacit knowledge, see (Polanyi 1983).

language, such as technical terms, poetry and songs, but also by other forms of ritualized social behavior such as artistic or religious performances and productions. Second-order local knowledge is internally represented by mental models referring to processes of knowledge production, justification and transmission to local social structures and cultural constructs. It may thus be externally represented by social structures, such as the institution of the oracle of Delphi in ancient Greece or that of the above-mentioned *pajé* in Brazil. Second-order local knowledge, however, may also be represented linguistically, for instance by religious or literary tales about knowledge, or simply by linguistically transmitted epistemological common places characteristic of a particular culture. One example discussed in Part 3 is the association between historical development, including that of knowledge, and seasonal growth and change common in Chinese culture.[21]

Historically transmitted second-order frameworks are typically less affected by changes of technology, environment or new information than is first-order knowledge, being more removed from immediate experiences. First-order knowledge tends to lose its relevance when contexts change. Its preservation is also endangered when external representations on which its transmission relies disappear, as when a native language is extinguished or when the corresponding material culture—for instance, the production and use of canoes in Micronesia—vanishes. Second-order knowledge, in contrast, is more durable not only because its relevance for intellectually mastering the world is less dependent on specific contexts, but also because its external representations are more resistant to changes. Epistemological common places as well as relevant tales, for instance, may be transmitted across linguistic and cultural barriers. Thus second-order local knowledge has in general proven to be more resistant to the challenges of globalization than first-order local knowledge. Local social structures such as family, ethnic groups and religious affiliations play a role in the regulation of the production, authorization and transmission of knowledge and may survive and even spread, when other, more large-scale social structures, such as political institutions, have long become victims of globalization.

Thus for instance, even when first-order knowledge about HIV/AIDS infection becomes widely available in a country due to governmental and non-governmental campaigns, the behavior of local people toward the disease remains largely governed by traditional second-order knowledge shaped, for example, by the dynamics and conflicts of family and clan relationships—and even by mentally assimilating the disease to witchcraft and disorders supposedly caused by the non-observance of ritual prescriptions.[22] At the same time, new forms of second-order knowledge may emerge from new types of situations, such as encounters between international development experts and local practitioners.[23] Such encounters require and generate a specific form of meta-knowledge, making it possible to move back and

[21] See chapter 17.
[22] See chapter 22.
[23] See chapter 21.

forth between local and globalized knowledge. Such newly emerging local second-order knowledge, however, is itself conditioned by the global history of knowledge and in particular by the demise of colonialism, which would have left little room and no legitimacy for such switching back and forth between different epistemic perspectives, one globalized, the other local. Still, the articulation of these perspectives and of the results of their encounter remains mostly local and implicit so that its overall impact on development policies is limited.

16.5 Modernization Without Alternatives?

With regard to the space available for negotiation between global and local knowledge, the situation looked entirely different at the beginning of the twentieth century. All over the world, social and intellectual elites were attracted by the apparent superiority of the Western trajectory into the modern world or were directly recruited in its service. The globalization of knowledge about modernization and its opportunities, in which these elites took part, anticipated other globalization processes. They thus contributed to a generally expected alignment of traditional societies with the Western paradigm. Alternative pathways involving what had remained of the world's variety of local knowledge traditions were being increasingly obliterated. In short, at the beginning of the twentieth century, the place of local knowledge seemed to be confined to niches soon to be eradicated by the expansion of Western economic, political and epistemic power. The gradual repression of local knowledge corresponded to the disempowerment and pauperization of the majority of people outside Western countries. In large parts of Latin America, for instance, land taken away from indigenous peoples by the privileged classes severely undermined their living conditions. In Africa, the natives were exploited as cheap labor, if not as slaves and cannon fodder in colonial wars. In Asia, even where local people were able to keep their governmental rule as in China, or at least local administrative structures as in India, they nevertheless became second-class citizens in their own countries.

While local populations still relied in part on traditional knowledge for their subsistence, at the same time they were affected by modernization processes such as urbanization, monocultural farming, large-scale cattle breeding, the industrial exploitation of primary resources, militarization or colonial warfare, inducing the loss of traditional knowledge. In many instances, local resources were drained further by the spread of epidemic diseases which reduced the size of human as well as animal populations and weakened their resistance to newly expanding economies and political regimes. As a result, people became increasingly dependent on a globalized economy which in contrast to their traditional ways of subsistence, did not offer them sustainable living conditions, unless they belonged to those elites who profited from such partial modernization processes. At the same time, however, with the diffusion of Western influence, water management, public health and education became societal issues—in some regions for the first time—which contributed to improved living conditions, for at least some of the population. Missionary activities, mass media and the education of at least a small part of the indigenous population enhanced the globalization of scientific and technological knowledge.

In all, these processes led to a sharpening of social contrasts and to a disintegration of societies, which were deprived of their potential to develop autonomous responses to the challenges of political and economic globalization by drawing on their own local knowledge traditions. The abdication of local elites, who pursued only their self-interests and their exploitation rather than leading the local population, contributed to this loss.[24] As the example of the self-colonization of Chinese intellectuals at the beginning of the twentieth century illustrates, under the conditions of global colonialism, even local perspectives on the possibilities of emancipation were likely to be determined by the sole legitimacy of Western second-order knowledge about the progress of science and its coupling to the progress of society.[25] Self-colonization is understood here as a process in which local actors identify with global epistemic frameworks fostered by dominant political and economic powers to empower themselves as well as their developing country by replacing local with globalized knowledge.[26]

Yet, without residual traditions, without the creative appropriation of globalized knowledge, and without new local responses to these challenges—including the adaption of new foods to traditional eating habits or the recycling of waste—for many survival would have been impossible. At the same time, local religious traditions, traditional social structures like family and clan relations, and other important factors shaping second-order local knowledge such as locally shared views about the role of an individual in society, or about gender and racial issues persisted. Occasionally, such traditional social structures assumed new meanings and new significance due to new circumstances, for instance with the potential of new military technology or new economic contexts to boost traditional rivalries into wars of extermination. But at the beginning of the twentieth century, the overall importance of second-order local knowledge remained confined, or so it seemed, to local and regional domains, without any chance of becoming relevant on a par with the globalized Western paradigm of progress and modernization.

16.6 The Unexploited Potential of Local Knowledge in a Post-Colonial World

This situation changed only when Western political, military and economic competition escalated into the world wars of the twentieth century, which substantially weakened Western political and military hegemony and opened up spaces

[24] This is explicitly reflected, for instance, in the autobiography of Mahatma Gandhi (1948).
[25] See chapter 17.
[26] This is also discussed by Albert Memmi (1967) who refers to the apparent inutility of the local or vernacular languages of colonized people who see all advantages in the language of the colonizer.

for the global spread of and experimentation with a variety of models for societal development, such as nationalism, militarism, socialism, democracy or religious fundamentalism, mostly still rooted in traditions of modern Western thought.[27] By the end of the 1960s, most of the former European colonies in Africa and Asia had become independent. The young states emerging from former colonies, however, were shaped by their historical heritage in ways that hardly any of these models were capable of coping with. Having served as suppliers of natural riches to industrialized countries, the economies of new nation states were one-sided, characterized by monocultures and highly dependent on the price fluctuations of the world market. Typically confined by artificially drawn boundaries, these states were further characterized by ethnic conflicts, often enhanced by colonial privileges for specific parts of the population, by diverging social differences and by the general lack of infrastructure for medical care and education. In addition, they continued to be dependent on industrialized countries, which did not hesitate to intervene when their own economic and political interests were concerned, even with military force. Examples are the military interventions of Japan in China, of France in sub-saharan Africa and those of the United States in Latin America.

Against this background, models of modernization with European origins were being reinterpreted and in part reinvented. Thus socialist ideas, which originally spread in Europe in response to the devastating social consequences of capitalist industrialization, had become, through their adaptation in Russian Bolshevism, part of a globalized ideological framework fostering the transformation of traditional societies. After World War II, they turned into an important point of reference for shaping the newly gained autonomy of post-colonial states. Such transformations were often still forms of transplanting versions of Western modernization top-down and often by brutal force into non-Western countries. In contrast to colonialism, however, the spread of such models of modernization was driven at least in part by a globalization of knowledge, in particular, about the political and economic options of developing countries to respond to the external pressure of industrialized nations and of the world market. Moreover, these models were often adapted to local circumstances, giving rise to autonomous solutions of developmental problems. These localized models were connected with high hopes for young nations to become independent actors in a globalizing world. Socialism in Tanzania, for example, centered on localized ideas about self-reliance, communal living and the African family. In most cases, however, such original solutions did not turn out to be sustainable due to external pressures.[28] In fact, the spread of alternative models of modernization was more often than not instrumentalized as a vehicle

[27]For a general discussion, see also (Eisenstadt 2000, 2002; Diawara 2004; Randeria and Eckert 2009).

[28]See the famous text by Frantz Fanon, first published in 1958, in which he deals with the post- or rather neo-colonial situation of African people between the blocs of the Cold War. He expresses quite a global view: “The future of every man today has a relation of close dependency on the rest of the universe. That is why the colonial peoples must redouble their vigilance and their vigour” (Fanon 1970, 136).

of neo-colonialism and global imperialism, particularly during the period of the Cold War. Under these circumstances, the affiliation of a particular country with the Western or Eastern alliance or its relevance as a provider of primary resources were generally more relevant to its eligibility for foreign support or its exposition to military interventions than its actual capability of improving the living conditions of the population according to a particular model, be it socialist or Western democratic. The immunization of models of modernization against modifications due to local knowledge is evidently furthered by the role of these models to defend claims to power in a post-colonial world, from the ideological confrontations of the Cold War to the War against Terrorism in our times.

Under these external pressures, the capability of such models to integrate local knowledge into a global learning experience remained limited. This was due in part to the immense inequality of power relations between developing and developed countries, but in part also to the inflexibility of Western thinking which hindered productive reactions to experimental variations of developmental models. As a result, experiences with the success and failure of the implementation of different models of modernization, in particular during the period of the Cold War, were often accumulated only on the level of ideological debate, without taking into account potential modifications induced by local knowledge. There were, however, remarkable exceptions, even in the contentious economic domain. In 1944, the Bretton Woods Conference, under US and British leadership, established rules for international economic policies, reversing the pre-war emphasis on protectionism and fostering the expansion of international trade. State interventionism according to the Keynesian model was an essential part of the Bretton Woods system, dominating international economic policies until the beginning of the neoliberal era in the early 1970s. The International Monetary Fund (IMF), the World Bank and the World Trade Organization (WTO) were all founded in its wake. On closer inspection, however, it did not amount to spreading a universal paradigm that was then identically reproduced, but left room for experimentation, adaptation and cooperative learning among different countries. As the example of the rapid spread of the central banking system, a key element of the Keynesian model of state interventionism, shows, local experiences and their exchange, in particular among developing countries, could play a key role in the transformation of this model.[29]

In the long term, local knowledge as well as other locally diverse conditions has played a crucial role in the differential development of non-Western countries since the 1970s. Practically all expectations concerning generic patterns of development were ultimately disappointed. Socialist models did not work as conduits toward a more equal distribution of wealth, either internally or with industrialized nations, nor did protectionism, and a reorientation from the world market toward South-South collaborations necessarily lead to an autonomous modernization of developing countries. And neoliberalism, with its request to deregulate local

[29]See chapter 20.

economies and open them toward the world market, did not bring such countries into alignment with the industrialized part of the world. Yet, substantial economic development in the so-called Third World did take place and was spurred by diverse conditions, from exploiting the local control over oil as a global key resource by Arab feudal regimes to the reorientation of local economies toward global exports by the "Asian Tiger" states.

Since the 1980s, a general trend can be observed for disseminating democracy, for strengthening the role of religion and for the spread of infectious diseases. Parallel to the dissolution of the Eastern bloc, authoritarian regimes were increasingly substituted by democratic ones in Latin America, in Africa and in Asia. These developments reflect the dependency of the success of a particular trajectory on specific local conditions, including its historical roots, as well as the capability of entire countries to learn not only from their own historical experience, for instance about the failure of authoritarian regimes to cope with the economic crisis, but also from those of others. In fact, the rapid economic development of certain Asian countries in recent decades could have hardly happened without the existence of ancient local traditions of cultivating knowledge as a way of self-improvement, such as Confucianism, nor without some countries (Hong Kong, Taiwan, Singapore and South Korea) serving as models for others (Indonesia, Malaysia and Thailand) (Dirlik 1995; Kim 2000). In contrast, Pentecostalism gained a stronger foothold in Latin American countries, as did Islam in Central Asia (Martin 1990). The 1980s and 1990s were further characterized by the increasingly global significance of infectious diseases such as AIDS or tuberculosis (Kaufmann 2009).

Global experiences nevertheless continued to play a limited role in guiding national and international policies. Indeed, the prevailing global structures fostering economic and infrastructural development still made insufficient use of experiences with differential local developments.[30] Development policy essentially began in the 1960s after the demise of colonialism on a global scale. Planned humanitarian interventions, characteristic of today's development policies, are embedded in dominant globalized organizational frameworks, imposing second-order frameworks on joint projects involving foreign experts and local actors. The experts are part of an international community consisting of engineers, agronomists, medical specialists, economists, lawyers and social scientists, engaged in pilot projects and humanitarian interventions. They have developed a highly specialized corpus of knowledge shaped by experiences with specific infrastructural challenges and global policies of development. This knowledge, as a rule, is put into operation under a logic of local technological or infrastructural success as measured by globalized standards within globalized epistemic frameworks. Actual success, however, is largely governed by factors outside their control, such as local political, economic and cultural conditions.

The first-order technological and scientific knowledge brought by the development experts is unavoidably reinterpreted and altered as a result of the encounter

[30] See chapters 21 and 22.

with local knowledge, including the second-order local knowledge about how such practical knowledge is to be implemented. Second-order local knowledge, and in particular the newly emerging second-order knowledge molded by the encounter between local and globalized knowledge, is universally effective in modulating the spread, appropriation and further development of knowledge. Nevertheless, what typically happens in such situations of epistemic heterogeneity conditioned by political and economic inequality is that this newly emerging local second-order knowledge is hardly articulated: instead, the procedural component is emphasized, that is, knowledge is generated and implemented about how to keep conflicts under control, by administrative measures, by bracketing or suppressing problems, or by brute force against some of the problem solvers. As a consequence, the newly emerging local knowledge about how to manage the practical challenges of waterworks, medical care or school education often barely feeds back into globalized epistemic frameworks, other than in an ad hoc manner. For the most part, it remains tacit knowledge. In this way, the significant transformative ability of local knowledge, which is often highly contested and subject to modifiation, remains unexploited.

16.7 The Generative Ambiguity of External Representations

The question of how to articulate knowledge brings us back to the issue of its external representations. External representations of knowledge, as a rule, have no uniquely fixed relation to internal, mental representations. Apart from the general ambiguity of say, language, two particular aspects are of interest in our context, both pertaining to what one may call the generative ambiguities of external representations: when individual knowledge is built up from shared external representations in the process of appropriation, ambiguities and individual variations emerge, giving rise to both misconceptions and innovations. External representations of knowledge often serve to express knowledge of quite different layers of reflexivity, as when, for instance, the equation $5 + 7 = 12$ is used as an example of arithmetic, of number theory, or of the synthetic a priori in the sense of Kant's philosophy. In using external representations for communication, in particular in cross-cultural contexts, this creates an inherent uncertainty about which layers of reflexivity are involved. Clearly, this particular ambiguity of external representations is a trace of their original role in generating such different layers of reflection in the first place, as there clearly would be no number theory or Kantian epistemology without the external representations of arithmetic historically preceding them.[31]

This generative feature of external representations may be enhanced when they are employed in the encounter between local and globalized knowledge. Here they typically serve as borderline objects to which different systems of knowledge are applied, thus connecting them, typically with repercussions on both sys-

[31] See chapter 6 and (Damerow 1996, 379).

tems involved.[32] External representations of globalized knowledge, such as books, databases or medical prescriptions, are used to reconstruct the knowledge transmitted from the perspective of a local culture. In this process of appropriation, such knowledge is reconceptualized in ways that strongly depend on second-order local knowledge and may even be shaped by first-order local knowledge, as when a compass is integrated into a system of navigation based on local astronomical and geographical knowledge.[33] The reconceptualization of globalized technological and scientific knowledge within the local setting of a developing country may entail entirely different social and behavioral implications of such knowledge in comparison to those associated with it under the assumption of "rational" and "autonomous" individuals employing such knowledge. As we discussed above, the transmission of basic knowledge, for instance, about HIV infection and about what the risks of certain behavior are, does not necessarily lead to appropriate changes in behavior helping to contain such risks. Local second-order knowledge may simply not offer any mechanisms by which new first-order knowledge can lead to such behavioral changes, at least on a collective level.

Such changes may rather be induced if second-order local knowledge changes as well, as when for instance new social communities emerge, and with them new role models and new identities for individuals, allowing them to assimilate such new knowledge in a more consequential way.[34] In this way, social structures, as we discussed above, serve not only as external representations of local second-order knowledge but also as conduits (or hindrances) for the assimilation of first-order globalized knowledge. It is for this reason that more recent developmental policies have drawn the conclusion that the transmission of such first-order globalized knowledge may make effective use of new role models and new identities for individuals, such as that of the "self-empowered" individual or of the individual "living positively" with the disease. Now these role models are also supposed to serve as conduits and external representations of the globalized first-order knowledge about HIV infection and associated behavioral risks. As a matter of fact, however, the efficacy of endogenous social representations and embodiments of local second-order knowledge can hardly be matched by such externally imposed role models, unless they happen to resonate with already existing social structures, such as those of more globalized urban environments.

When external representations act as borderline objects under conditions of epistemic heterogeneity, their generative properties may be enhanced, as mentioned above, possibly inducing new forms of local knowledge. An example are local objects, be they natural, artisanal or artistic, that make sense both from the perspective of local culture and from that of globalized knowledge, embodying, for instance, abstract mathematical structures. In this way, they may open up new ways of appropriating such globalized knowledge, and at the same time connect

[32]See chapter 21.
[33]See chapter 19.
[34]See chapter 22.

it with specific local experiences at both the first, and second-order level. Thus Guarani children in Brazil may learn the mathematical concept of symmetry on the basis of the indigenous practices of basket-weaving and body painting, and at the same time experience, so to speak on the second-order level, the possibility of connecting local and globalized knowledge.[35]

Alternatively, under conditions of epistemic heterogeneity, external representations may enhance the formal, material and procedural aspects of knowledge and knowledge transmission. This typically happens when cooperation is enforced under extrinsic or intrinsic pressures, emerging from the necessity, for instance, to complete a local development project funded by international sources. In this case, accountability is enforced as a globalized second-order epistemic framework embodied in external representations, such as lists, standard forms, time-sheets, workflows and databases. Yet at the same time, even such external representations of formal knowledge display the characteristic generative ambiguities mentioned above. Due to their role as borderline objects, mediating between local and globalized knowledge, they are amenable to alternative interpretations depending on different contexts of justification, for instance within and outside specific negotiations. They thus enable the development of the previously mentioned meta-knowledge making it possible for development experts to move back and forth between local and globalized knowledge. As long as such meta-knowledge does not itself find an external representation beyond these ambiguities it must remain entirely ad hoc, thus constituting merely practical, local second-order knowledge. In other words, the globalization of such second-order knowledge also depends on the emergence of more encompassing forms of external representations, involving not just procedural aspects, but also first-order local knowledge as well as reflections on the concrete social experience of the cooperation itself. In view of this latter component, more encompassing external representations of this kind will probably have to take the form not only of written accounts or formal procedures, but also that of new forms of social organization suitable to contain and transport the second-order knowledge acquired in such experiences. These experiences could enter, for instance, into the curricula of school and university teaching, offering novel perspectives on the possibilities of contextualizing scientific and technological knowledge.[36]

16.8 The Four Phases of Knowledge Transmission

In the following, we consider the encounter between globalized and local knowledge from yet another point of view: the overall dynamics of knowledge transmission. This perspective confirms what we have learned from examining the role of external representations in such encounters, namely the existence of an inherent potential in these processes for enhancing the autonomy of its participants.

[35] See chapter 23.
[36] See chapter 25.

Knowledge transmission processes may be triggered by the spread of innovations due to commerce, war, religious missions or chance encounters. Examples are the assimilation of new eating or clothing habits by Brazilian native populations, or the arrival of new boat technology in Micronesia.[37] They may be intentionally imposed on a local culture from the outside for political, economical or ideological reasons. Examples of this are the transfer of water management infrastructure or medical procedures by development projects to under-resourced African settings.[38] But knowledge transmission processes also may be engendered by factions of a local population, as when Chinese elites began, at the beginning of the twentieth century, to search for ways of emulating the Western trajectory toward modernity and constructing communicative networks to serve as conduits for the transmission of globalized knowledge.[39]

In all of these cases, the transmission of globalized knowledge into cultural settings shaped by local knowledge proceeds as a multilayered process within a global interaction sphere, with different kinds of transformations happening more or less simultaneously in the different layers. But knowledge transmission is layered not only in a synchronic but also in a diachronic way, as earlier globalization processes may significantly condition later encounters between globalized and local knowledge. For instance, local languages may or may not have been lost, a circumstance that significantly changes the conditions for preserving local knowledge, as the different examples of the Tupinikim and the Guarani populations in Brazil illustrate.[40] Moreover, one such historical differentiation also engenders, as a rule, a divergence of other sociocultural traits in subsequent development. Earlier historical events may have led, in particular, to quite diverse learning (or suffering) experiences in dealing with the encounter between local and globalized knowledge.

The encounter between globalized and local knowledge encompasses four analytically, not temporally, distinct phases. First, the global interaction sphere determines the conditions for any kind of transmission processes, including the accessibility and transfer of globalized knowledge. Such transfer often begins with rather mediated, indirect and unintentional activities, as when industrial products arrive more or less accidentally in a context where they have been previously unknown. Gradually the transfer then becomes more immediate, more direct and more intentional, as when such products are directly acquired or even reproduced in a local context. Second, globalized knowledge is localized, that is, recontextualized, selected, appropriated, transformed and institutionalized according to the locally dominant epistemic constellation. This happens, for instance, when technical equipment is re-engineered or set into a new social context to serve local purposes. Third, knowledge is transformed, that is, obliterated or modified by

[37] See chapter 19.
[38] See chapters 21 and 22.
[39] See chapter 17.
[40] See chapter 23.

the contact with globalized knowledge or else superimposed on it, with first-order local knowledge often being extinguished or strongly modified, and second-order local knowledge often being somehow blended with globalized second-order knowledge. Thus, local knowledge about health may change as a result of contact with globalized knowledge, by dismissing local healing practices while merging the local understanding of the social context of health with globalized standards of healthy behavior, for instance, in terms of sexual relationships or family ties. Fourth, genuinely new knowledge about the material or the social world may arise as a result of the encounter between local and globalized knowledge, as when new pharmaceutical products become possible on the basis of integrating indigenous knowledge about plants into globalized biochemical knowledge, or when new forms of social interaction are developed from experiences gained with knowledge transfer.

As a result of the multilayered structure of the transmission of globalized knowledge into local settings, the global availability of technologies and technological products does not necessarily imply the spread of globalized knowledge systems. Both global and local conditions may even totally block this spread, as when Japan isolated itself from foreign influences over centuries. In general, however, transmission processes are not prevented but merely lead to unexpected outcomes. Thus, the spread of the outboard motor on boats as a convenient substitute for more traditional techniques of locomotion, as one might have expected, does not entail the spread of globalized navigation techniques.[41] And the spread of a globalized technological infrastructure, of medical treatments, or of mass media does not necessarily go along with the same kind of changes in social structure and in the corresponding social knowledge that accompanied the original establishment of these achievements in technologically advanced societies. Yet, the transfer of technologies and technological products is associated not only with technical and scientific knowledge, but also with certain models of rationality as well as with cultural and social knowledge, in particular about the possible goals and values of the use of such technology. This added-on component of transferred globalized knowledge is due in part to the internal logic of technological systems which only work as intended in specific social contexts, and in part to the global conditions of transfer imposed by the more powerful side of the interaction sphere.

This “inscription” of globalized norms and values into technology transfer may even appear to be a largely deterministic process, leaving little room for the receiving end to creatively appropriate and transform the results of the transfer according to local norms and values.[42] Such a view, however, would underestimate the complexity of a knowledge transfer process and its inherent potential for enhancing the autonomy of its participants. When technology serves as an external representation of knowledge in such transfer processes, it intrinsically develops, as we have discussed above, generative properties, opening up a larger horizon of possible uses than that originally envisaged by its manufacturers. Furthermore,

[41] See chapter 19.

[42] See, also for the following, the discussion in chapter 21.

an epistemic vacuum does not exist. Globalized knowledge is always matched with local knowledge, and this encounter typically triggers transformation processes with novel consequences, occasionally at the level of first-order knowledge and virtually always at the level of second-order knowledge about the reflexive self, about role models in society and about the meaning of knowledge. This is so because when actions must take place, for instance in cooperative ventures under conditions of epistemic heterogeneity, then they must also be accompanied by reflections lending them meaning. These reflections necessarily combine local and globalized knowledge; they affect the understanding of norms and values, but they typically do not yield results fitting into the pre-existing local or globalized systems of knowledge. As we have also discussed, they hence tend to be of a merely ephemeral character, being expressed in terms of a meta code articulated outside the established systems of representation and merely in local contexts. The spontaneous development of such meta codes nevertheless harbors the potential for more encompassing reflection, and accordingly for a more conscious steering of knowledge transfer processes in which the norms and values that seem to be inextricably linked to and “inscribed” into technology can actually be spelled out and thus debunked.

16.9 The Global Context of Encounters Between Local and Global Knowledge

When considering the opportunities to develop such local experiences into more general perspectives, one should not forget the global conditions for implementing them in concrete policies. Otherwise one risks mystifying the epistemologocal complexities of these experiences as they are revealed in studies focusing on specific local settings, and overlooking their dependence on the larger historical development which may affect the interaction between local and global knowledge in fundamental ways.

The dynamics of the world market, and in particular of the world financial market, radically affects the field of policy options in ways that may counteract any perspective for sustainable development (Mosley 2003). Until the beginning of the 1970s, exchange rates had been pegged to the US dollar (and the dollar fixed to gold). In addition, to maintain the pegged exchange rates, most countries used capital controls. This arrangement isolated developing countries from international financial markets and enabled them to borrow money and maintain a current account deficit without the risk of “speculative attacks.” The problem with this arrangement was that the United States served as a global source of liquidity. The situation led to a growing current account deficit in the United States, which financed the trade surplus of Germany and Japan. By 1971, US gold coverage had fallen dramatically and within a short period of time the international monetary system shifted from pegged (but adjustable) exchange rates to floating exchange rates. This change was accompanied by many countries lifting capital controls

(Eichengreen 1996). The new international monetary regime put growing pressure on developing countries because they were no longer isolated from international capital flows (Fischer and Reisen 1993). In addition, with the liberalization of financial markets, developing countries had to compete for Foreign Direct Investment (FDI) by providing more favorable conditions for foreign capital, a process that at least in some cases led to a "race to the bottom" (Froot 1993; Jensen 2006). The new international situation required developing countries to undergo fargoing structural adjustments, a process that was accompanied by financial and economic crises.

Also, when credits were cheap in the 1970s due to an excess supply of capital on the international financial market, many developing countries made use of this opportunity to launch overambitious projects for creating infrastructure and building up industry that could not be maintained from their own economic momentum. In the 1970s, developing countries were also struggling with the consequences of the international oil crisis and the global economic recession. In addition, in the 1980s, interest rates were going up and capital wandered to the United States, as a consequence of its neoliberal politics with tax reductions and increased military expenses financed by credit. Many developing countries were thus unable to pay their debts. Eastern and Southern African countries, for instance, stood on the verge of economic and political collapse.[43]

As a consequence, poor countries now became even more dependent on support and interventions by the West, for instance in the form of financial aid by the IMF and the World Bank, institutions dominated by rich countries. Such aid aimed at macroeconomic stabilization and at paying off national debts. At the same time, it has become more customary that Western donor countries connect developmental aid with requests for human rights, limitation of military budgets, the fight against corruption and for democratization, in particular since the collapse of the Eastern bloc. In any case, since the mid-1980s, developmental policy has been increasingly geared to structural adjustment programs, ensuring the economic viability of aid projects, again as measured by globalized standards.[44] Such globalized standards for development and structural reforms typically comprise requests for currency devaluation, deregulation, and the reduction of trade barriers, privatization of state-owned enterprises, reduction of public spending for healthcare, education and housing programs, and requirements of accountability. In Tanzania, for instance, such policies led to a growing deterioration of the public health care system, imposed unbearable costs for medical care on the poorest strata of population, and made the country's health care system increasingly dependent on external funding.[45]

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[43] See (Anders and Münter-Elfner 1999; Nitsch 1999), see also (Strange 1997, Table 1.2, 17) and http://www.ritholtz.com/blog/2010/08/history-of-us-interest-rates-1790-present.

[44] See (Goldstein 2001; Drazen 2002; Khan and Sharma 2003; Vreeland 2003; Akonor 2006).

[45] See (Collier 2007; Easterly 2006; Anderson 1999) and chapters 21 and 22 in this volume.

The reform programs introduced by the IMF and the World Bank in the 1980s thus imposed the priorities of international donors and development experts on national and local governing bodies, ignoring domestic differences.[46] At about the same time, however, development experts became increasingly aware of the necessity to also integrate local knowledge and expertise into the planning, organization and implementation of local development programs and projects. They realized that the modernization paradigm of development from the 1950s and 1960s, which focused essentially on economic development, had often failed due to its neglect of social and cultural factors and contexts. Nevertheless, holistic models tailor-made for individual countries had and still have hardly a chance of being implemented with the help of international developmental policies governed by globalized priorities and standards. Such models would take into account the entire complex of historical, cultural and social conditions of the given country, as well as local knowledge, for instance, about social cohesion, natural resources and the environment. They would also include the lessons since learned about the entanglement between the transfer of technical and scientific knowledge and changes in worldviews and social organization, for instance concerning the relation between the spread of biomedical knowledge and the modification of local views and cultural practices.

Still there are numerous initiatives worldwide that are guided by the idea of reconciling local cultures and identities with the non-native knowledge that is necessary to live together in a more global society.[47] Such projects—which may be of an educational nature but also take the form of internationally mediated political negotiations about local conflicts—renounce the imposition of supposedly universal standards, methods and values and contribute instead to a globalization of knowledge in the sense of spreading the competence to contextualize globalized knowledge by integrating local experiences and circumstances.[48] A wider spread of such endeavors might go a long way toward strengthening the capability of developing countries to find their own path into a globalized world, in particular when they also include higher forms of learning and new curricula that take into account the ideas of a "global contextualism."[49]

16.10 The Role of Local Knowledge as a Matrix of Globalization

In the end, individual modifications of second-order frameworks, resulting from and in turn shaping the interaction between globalized and local knowledge in practical experiences "on the ground," create the unpredictable patterns according to which the globalization of knowledge unfolds. Thus, in spite of the influence

[46] See (Goldstein 2001) and for a more general criticism of globalization (Rodrik 1998).
[47] See (Morin 2001; Hessel and Morin 2012).
[48] See chapter 23; for an example, see also the initiative "Heidelberg Darfur Dialogue" by Rüdiger Wolfrum (Mayer 2005; Wolfrum 2010).
[49] See chapter 25.

of self-colonization on Chinese intellectual elites, modernization in China eventually followed a trajectory that was essentially shaped by modifying globalized ideas about modernization according to specific local traditions and experiences. (This, however, did not prevent tremendous human sacrifices.) Even unpredictable and sometime serendipitous contributions by individuals can make a huge difference to the globalization of knowledge.[50] In the Chinese case, the supposedly stringent and universal intrinsic logic of the Western example, prescribing specific couplings between economic and political developments—for instance between the introduction of a market economy and that of a democratic society—was invalidated, albeit not completely. The same mechanism of partial disintegration and remodeling can be observed on all scales. For instance, the introduction to Micronesian seafaring of modern boat technology—associated in a globalized context with equally modern navigation techniques—does not necessarily preclude the revival of navigational knowledge strongly bound to the local context, although it does entail the loss of traditional sailing techniques.[51] Similarly, the technological improvement of waterworks in Tanzanian cities in the course of developmental aid is not necessarily accompanied by a successful transfer of the organizational structure required to run these waterworks according to globalized standards.[52] Yet the failure of this transfer ultimately led to follow-up projects dealing with precisely this issue, albeit in a way not fully determined by these globalized standards. Similarly, the transfer to local African communities of globalized knowledge about causes of HIV infection and measures to prevent it does not necessarily lead to changes in social behavior that correspond to the expectations originally associated with this transfer.[53] Yet obviously, the transfer of such primary knowledge is always coupled with an interaction between second-order frameworks. This interaction also ultimately shapes the result of the encounter between globalized and local knowledge, for instance, by giving rise to new, locally emerging forms of social behavior responding to the challenge of the disease, and both the knowledge and technologies for coping with it. The partial disintegration and remodeling of globalized epistemic frameworks in the course of such encounters between local and global knowledge may act as a source of innovation in comprehensive globalization processes, including their political and economic dimensions.

The place of local knowledge in the global community is not a niche but a matrix, a substratum of all other forms of knowledge generating diversification and change. With the evanescence of local ways to master practical challenges, driven by economic and cultural globalization processes as well as by the inexorable spread of globalized technological and scientific knowledge in their wake, local knowledge may appear to be generally on the decline. There is no spread of knowledge, however, without inevitably local efforts to make sense of it. Cer-

[50] See chapters 17, 18 and 26.
[51] See chapter 19.
[52] See chapter 21.
[53] See chapter 22.

tainly, these local efforts are themselves shaped by the globalization of knowledge, including globally diffused second-order frameworks determining how knowledge is to be gained, understood and used. But these globalized frameworks are themselves deeply influenced by local second-order knowledge, which is less evanescent than first-order local knowledge. It is indeed much easier to interlace—or undermine—these globalized second-order frameworks with local ideas and behavioral patterns channeling the ways in which knowledge is being authorized, appropriated and adapted than it is to preserve local knowledge about traditional technologies.

Globalized second-order frameworks only appear to be dominant as long as one focuses on the level of explicit articulation. Their actual dominance in terms of mastering real-life challenges is another matter. Here, it is typically a mixture of globalized and local frameworks that governs the actual processing of knowledge. In other words, local knowledge is still significant, albeit implicit, in traditional social structures, requirements effectively imposed by ecological conditions, by historical contingencies, or by the locally variable conditions resulting from economic globalization. Such local knowledge has less to do with orientation in the forest or with the manufacture of tools, and more with coping with the incidents of life under conditions that are simultaneously local and global. This hybrid second-order knowledge provides a framework in which other kinds of knowledge, be they local or global, make sense. Such knowledge is always in flux, as are the identities and role models with which it is associated. It is rarely articulated in a direct way but rather tends to hide behind more conventional forms of external representations. Technological artifacts, construction manuals, databases, religious or scientific texts may all harbor such knowledge which is activated when such external representations serve as borderline objects under the conditions of epistemic heterogeneity. Accordingly, hybrid second-order knowledge typically presents itself differently from the perspective of different actors. Yet it is more than the meta-competence of code-switching that allows the actors to simultaneously participate in diverse systems of knowledge. As second-order knowledge is never completely decoupled from first-order experiences with the material and social reality, it also represents a form of knowledge about the real world.

Local knowledge hence remains the underground from which all other forms of knowledge emerge, not in a primordial sense, but in terms of the inevitably local appropriation of shared knowledge, whether it is globalized or not. The immense variability of local conditions hence continues to act as a driving force for the further diversification of knowledge, even in the presence of globalization. The impact of this diversification on the globalization of knowledge, however, remains limited. This situation will prevail as long as hardly any forms of external representation are employed that would allow this multiform knowledge to be reflected upon, conceiving it as a collective human experience, available for shaping the globalization of knowledge with an increasing awareness of its conditions and consequences.

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Chapter 17
Taking China to the World, Taking the World to China: Chen Hengzhe and an Early Globalizing Project

Denise Gimpel

17.1 Introduction

In a lecture to a scholarly society in China in 1917, Cai Yuanpei (1868–1940),[1] Chancellor of the prestigious Peking University, announced that religion in western societies had long been replaced by scientific enquiry.[2] Religion's knowledge function—the provision of answers to fundamental questions that the human intellect was not yet developed enough to answer—had been a necessity of the past that scientific methods had rendered redundant (Denton 1996, 183). China thus needed to know that the West's past solution to a lack of knowledge (religion) was not a trajectory that the nation should copy. It belonged to the past.

China at this time, of course, needed a future and, in the eyes of many, it needed a future that would integrate it in global processes or what certain intellectuals or groups of intellectuals regarded as global or universal trends. After the failure of politics to provide the constitutional foundations of a new and modern republic following the so-called revolution of 1912 and the country's rapid decline into division and warlordism, Chinese intellectuals were, more than ever, as Jerome Grieder puts it, "between orthodoxies" (Grieder 1981, 289). Traditional worldviews had all but crumbled; politics had, clearly, not been able to create a stable basis. China had failed to gain a niche and respect in the international community. It was, of course, the orthodoxy of socialism (with Chinese characteristics) that was to win the day after 1949, but in the early twentieth century there were contesting "globalizing projects." According to Mao Zedong (1893–1976), for instance, the Chinese needed to be entered into the universal dynamics of world revolution and thus change their previous cultural habits:

> Since the great call for "world revolution" the movement for the "liberation of mankind" has pressed forward fiercely, and today we must change our old attitudes towards issues that in the past we did not

[1] For a good introduction to Cai Yuanpei's position and activities, see (Chow 1960), *passim.*

[2] The lecture was titled "On Replacing Religion with Aesthetic Education." For the original Chinese text, see (Gao 1984, 30–34). A translation can be found in (Denton 1996, 182–189).

> question, towards methods we would not use, and towards so many words we have been afraid to utter.[3]

For a more influential and elitist group of "globalizers" at roughly the same time, the world's revolution was encased in the concept of "science" and the scientific method. For these individuals, as for Cai Yuanpei, the concept of science was to form the basis of a new orthodoxy that would globalize China and lift it out of its past paradigms of cultural and social understanding and change old attitudes, methods and the very vocabulary of life and thought thus integrating China into the world's systems and laws. This scientific method was not limited to the study of the natural sciences. Although physics, chemistry, meteorology and the like formed an important aspect of the globalizing project, scientific principles were perceived as equally pertinent to almost all areas of life and activity.

Here it is clear that the understanding of "globalization" or the qualifier "global" at the center of this paper is not concerned with markets or economies, with direct foreign investment in China or with many of the other factors popularly associated with the term. Here globalization is understood as an impulse and a necessity felt by many Chinese in the early twentieth century to see China integrated into the world and its workings. The adjective "global" thus qualifies modes of thought, writing and being to which China was to aspire. It marks a target more often than a state or situation that had been achieved. Geographically, of course, China has always been a part of the world, but since the close of the nineteenth century Chinese intellectuals had increasingly felt it to be outside the international community of strong nations, and many of the reform projects of the time, whether aimed at Communist revolution or reform based on European or Anglo-American models, were predicated on a sense of outsideness and non-inclusion in world processes. This sense of outsideness was heightened by the fact that Japan, a small country that the Chinese had traditionally tended to look down upon, had indeed "globalized." The Japanese, whose Meiji reforms since the mid-nineteenth century could also be said to have been predicated on a sense of outsideness,[4] had integrated themselves into a world system, gained recognition and strength (enough strength to win a war against a European power in 1904) and even to push through their particular claims in Versailles in 1919.[5] The aim of the present paper is thus to present one of these projects and to uncover its background and its attempts at insititutionalization.

The following brief comments will be concerned with a concrete example of the manner in which a perceived universal "scientific" attitude or spirit was to be

[3] Translation taken from (Schram 1992, 318).

[4] Many reform attempts aimed at gaining the respect of strong Western nations. Japanese foreign minister Inoue Kaoru wrote in 1885, "What we must do is to transform our empire and our people [...] To put it differently, we have to establish a new, European-style empire on the edge of Asia." See (Mackerras 1997, 196–197). Inoue's remark is also cited here.

[5] For a brief description of the events at the Versailles Peace Conference, see (Clements 2008, 53–108).

imported to the Chinese context and thus take China into the world and establish the strong world's principles in Chinese thinking and behavior. When knowledge travels it requires a means of transportation. It arrives at a given destination through a variety of media, but most of all it is transported by human agency, by the individuals, groups or networks that have translated and processed it for a new context and with a clear purpose. Foreign missionaries, merchants, military and others had for a long time taken their "knowledge" and skills to the Chinese in order to change and/or modernize them, but from the first decades of the twentieth century, a group of native intellectuals was also involved in the processing of what they considered were vital forms of knowledge for a new China. This process of selective and inventive transmission of materials and ideas from a dominant culture has often been called "transculturation" and has largely been discussed in connection with the colonial enterprise.[6] In the present case, however, the imperial project plays a lesser role. The focus will be on the life, activities and writings of Chen Hengzhe (1890–1976), who in 1920 became China's first female professor of Western history at Peking University, and on the mechanisms by which she and others attempted to transmit what they believed to be global knowledge to the local, Chinese context. Questions will also be raised as to how such individuals gained and constructed their authority and how they produced new and authoritative interpretations of history, of the West, and of life.

Chen Hengzhe had studied history and literature in America between 1914 and 1920 (Vassar and Chicago),[7] she was a historian of the West and of the European Renaissance, author of short stories, essays, poems and fables and she is an excellent example of the type of transculturation many early twentieth-century Chinese intellectuals envisaged. Her life and her writings illustrate that she was part of a network of urban intellectuals, most of whom had studied abroad, who shared the desire to translate China into a country that subscribed to values, ideas, modes of thought and modes of being and social organization that these intellectuals deemed globally or universally applicable. Like others, Chen Hengzhe was a product of significant historical changes that facilitated intercultural experience and new imaginings of the cultural setting in which they lived. This, they felt, also demanded deep epistemological changes in China: new ways of writing, thinking and acting. Chen's trajectory, however, also shows that, although they all saw themselves as self-determined and, even, enlightened, leaders of a new generation, they were willing victims of cultural imperialism, self-colonization and hubris. Nevertheless, and despite the ultimate failure of their project, their influence and the influence of the categories of thought that they espoused and the institutions they helped to create was immense up to the Communist victory in 1949 and, in many ways, has been experiencing its own renaissance since the opening policies inaugurated by Deng Xiaoping in the late 1970s.

[6]See (Pratt 2009, 7).
[7]For a biographical sketch of Chen Hengzhe, see (Yang 1991).

17.2 Study Abroad and its Effects

Chen Hengzhe (or Sophia H. Chen Zen as she was known to her American friends) left China on 15 August 1914 on the S.S. China together with "over one hundred boy students from Tsing Hua College and fourteen girl students, nine of whom belonged to the Tsing Hua scholarship group."[8] Some twenty years later, when she wrote her *Autobiography of a Chinese Young Girl*, she records this event as a momentous one in China's history, as momentous for China as the outbreak of the First World War for Europe:

> It was significant that just as the world was waiting to be affected by the changes to be brought about by this tremendous armed conflict, China was also preparing for fundamental change in her national life through the sending of her young girls by the government for the first time. For these young girls were not sent abroad to make military or political contacts with the western countries, as many young men as well as special commissioners had been sent for previously; but they were asked to study the cultural side of the western nations. (Chen n.d., 188)

Thus Chen Hengzhe set off for the wide world and a future that was, in her own view, to have significance for the national life of China and its womenfolk. The result of this journey was, in her own words, "an intangible yet strong alliance" between East and West "not on the soil of the war-creating spheres but right within the hearts of the peoples" (Chen n.d., 188).

This, then, was the manner in which she saw her trip: a significant event in the development of China, a significant event in the public attitude to young women and a significant influence on China's place in the world. Clearly this is her rather inflated interpretation of her life *after the event*, but it characterizes her sense of mission during her studies and in her later writing. In his comments on biographical and autobiographical writings, Brian Roberts observes that "the recollection of past events is inextricably connected with people's current life and its place in the group and wider surroundings" (Roberts 2002, 104). And it is in this context that we should understand Chen's construction of the narrative of the purpose and results of her voyage: from the moment she arrived in the United States and even more so after returning to China, Chen's life was inextricably linked with, on the one hand, activities that were to devalue "Chinese" knowledge and to replace it with the more developed ideas and institutions of the "civilized world"; on the other hand, she consistently (re)constructed her own biography as that of the exemplary modern women (what China needed): self-determined, mistress of her own fate, educated, successful.

[8] *Autobiography of a Chinese Young Girl* (Chen n.d., 187–188). I must offer my thanks to the librarians at Vassar College for making this text available to me.

One of the early examples of these activities was the founding of the Science Society by Chinese students in America. In 1914 a group of students at Cornell University established an informal Science Society that was to become, one year later, the Chinese Scientific Society. Its mouthpiece was the journal *Kexue* (*Science*) that had been launched in January of the same year.[9] That this was an attempt to align China with what its supporters understood as global processes is clear from the editorial of the first issue. "It is science, and only science, that will revive the forest of learning in China and provide the salvation of the masses"[10] according to the inaugural statement, and an article in the first issue by founding member Ren Hongjun (1886–1961) explained why China did not possess any science and what this meant for the country.[11] The editor-in-chief, Yang Xingfo (1893–1933) explicitly related the founding of the Science Society to globally/universally pertinent processes when he wrote that "[a]ll civilized countries have established scientific societies to promote learning."[12]

However, the students behind this journal not only felt that China was in need of a different kind of scholarship, both in content and approach in order to join the ranks of the civilized nations, they also saw a need for a new mode of presentation. Thus, from the beginning, *Kexue* adopted Western-style punctuation and was probably the first in the history of Chinese journals to do so. Ren Hongjun felt that the Chinese needed quotation marks in particular (Fan 2004, 9). This is, in itself, a remarkable development since it points to the recognition of the worth of the individual statement (quoting one person's opinion or findings) as valuable, legitimate and objectively verifiable as opposed to citations from the (Chinese) Classics as a source of legitimation and as the ultimate (moral) orthodoxy.[13] Thus, the members of the society clearly felt, a national-cultural frame of reference for intellectual work was being replaced by a broader one with "universal" characteristics.

It was not only science majors who were present at the meetings of the Science Society. In fact the issue of punctuation had been brought up by a young student who was to become one of China's leading thinkers and writers, Hu Shi (1891–1962), who had initially chosen to study agriculture in America, but soon turned to philosophy. The history major Chen Hengzhe was also present.

The link between the humanities and the natural sciences was, in any case, a very close one at this time. No matter what the students were studying, their aim was to "save China," to introduce at all levels of society the scientific spirit that

[9] For a reproduction of the title page of the journal, see (Fan and Zhang 2002, 15).

[10] "*Kexue* fakanci" (Inaugural statement of *Kexue*) reproduced in (Fan and Zhang 2002, 14–18, 18). This translation is taken from (Wang 2002, 302).

[11] The article with the title "Why China Lacks Science" is reprinted in (Fan and Zhang 2002, 19–23).

[12] Cited in (Wang 2002, 301).

[13] Chinese had, of course, always had a means of identifying statements as quotations. However exact references were never given since the educated reader would recognize references and allusions. References to orthodox classical authorities were often prefaced with statements such as "The Book of Odes says" or "The Master [Confucius] said."

they felt their countrymen and women lacked.[14] Thus the chemist Ren Hongjun writing in *Kexue* in 1917 linked the cultural and political conservatism of China with a lack of progress.[15] In 1922 the biologist Bing Zhi (1886–1965) could speak on the connection between biology and women's education, taking the education of women as a must and their training in biology as a prerequisite for the eradication of superstition. Likewise the meteorologist Zhu Kezhen (1890–1974) criticized the unscientific methods used in China to counteract problematic weather conditions. Instead of praying for rain or slaughtering animals, the proper way to deal with "disastrous droughts or floods is to prepare for them before they come, by reforestation, by water conservancy, and by the establishment of a large number of meteorological stations" (Wang 2002, 307–308). Cultural habits were impeding development. In the 1930s Hu Shi wrote of the difference between Western scientists who had worked with natural phenomena and Chinese scientists who had worked with books and words. The result was, according to Hu, that the Chinese "created three hundred years of book learning" while the West "created a new science and a new world."[16]

These scholars were clearly not only trying to spread new ideas from the natural sciences; their concept of knowledge was directly linked to social progress and change that was conceived as linear and leading to improvement, to a place amongst the "civilized countries." Ren Hongjun also made this clear when he linked advanced knowledge of the material world with an advanced "view of life." Science, he felt, could affect the way people viewed and organized life and he saw proof of this in the course of history: the way people viewed life in the Middle Ages was quite different from the way it was now viewed in the light of the theory of evolution. This was evident in social progress,[17] the social progress displayed in *other* parts of the world. A change in spirit, attitude and mode of learning, acting and writing in China would make similar progress possible in China. In fact, it seems that these scholars thought that such change would come inevitably with the changes they put forth: they had found the translation formula and could now catapult China into the laws of the "modern" universe.

This then, is the project within which one must view Chen Hengzhe's writings and activities. On the surface its argumentation would seem sound enough; and yet we could also see her and her colleagues as the enthusiastic subjects of cultural imperialism. As Jean-Paul Sartre put it somewhat drastically in his 1961 preface to Franz Fanon's *Wretched of the Earth*:

[14] For a discussion of a similar project through popular literature, see (Gimpel 2001, especially chap. 2.).
[15] Cited in (Fan 2004, 18).
[16] See (Hu 1934, 70–71). Three hundred years refers here to the period from the seventeenth to the twentieth century. Hu Shi is comparing intellectual endeavour in the East and the West in this period.
[17] See (Fan 2004, 19– 20). See also Hu Shi's comments on the problems involved in the fact that "the Chinese view of life has never encountered science face-to-face!"; Hu Shi, *Kexue yu renshengguan xu* (Preface to science and the view of life), cited in (Wang 2002, 308–309).

> The European elite undertook to manufacture a native elite. They picked out promising adolescents; they branded them as with a red-hot iron, with the principles of Western culture, they stuffed their mouths full with high-sounding phrases, grand glutinous words that stuck to the teeth. After a short stay in the mother country they were sent home, whitewashed. These walking lies had nothing left to say to their brothers; they only echoed. From Paris, from London, from Amsterdam we would utter the words "Parthenon! Brotherhood!" and somewhere in Africa or Asia lips would open "…thenon! …therhod!" It was the golden age.[18]

Shame and a sense of cultural inadequacy (an inadequate orthodoxy) had prepared the minds of individuals like Chen Hengzhe to react positively to the Western discourses with which they were confronted at every turn in the early twentieth century. The discourses of science and democracy, of modern education and equality, were clearly predicated on societies whose national cultural strength made them exemplars in China's continuous and continuing search for national wealth and strength as well as global recognition. Chen, like others, was exposed to the new ideas through the press, schooling and word of mouth. At the same time foreign powers (in her case America) actively strove to train a Chinese national elite in their own image.

Like many other young people of the time, Chen Hengzhe read the newly available print media and was influenced by them and their presentations of the wonders of the modern Western world.[19] Her perceptions of different and new possibilities in life were mediated on the one hand, as she herself explains, by such towering figures as Liang Qichao (1873–1929), influential scholar-journalist of the period and Tan Sitong (1865–1898), martyr of the ill-fated but ambitious Hundred Days of reform of 1898;[20] on the other hand, she was fascinated by both Madame Roland (1754–1793) and Joan of Arc (1412?–1431). However, the image that she chooses to use as the focus of her life and writings is that of the will to achieve and shape one's own destiny (*zaoming*).[21] The concept had, she writes, been passed on to her by her maternal uncle together with an awe of active Western women. She fittingly frames her autobiography with this image, opening her text with a fable comparing the difficult and winding passage of the Yangzi River through mountains and into the sea with the man-made, dull and non-self-

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[18] Jean-Paul Sartre's preface to Franz Fanon's *Wretched of the Earth* (Sartre 1961, 1).

[19] It is impossible to go into the details of the Chinese press and its introduction of "things foreign" at the time in such a brief article. For a first glimpse of some of issues dealt with, see, for instance (Gimpel 2001; Vittinghoff 2002; Lackner and Vittinghoff 2004) and the detailed bibliographies offered there.

[20] See, especially, chapter 5 of (Chen n.d.). For basic biographical information on Liang Qichao, see (Boorman 1967, vol. II, 346–351). For Tan Sitong, see (Spence 1987, 51–53).

[21] See, for instance, her autobiographical essay *Wo youshi qiuxuede jingguo* (My early schooling) in (Chen 1995, 314–326, 315, 325; Chen n.d., 151).

determined course of the Grand Canal.[22] Her life, as she saw it in hindsight, had been a difficult path to a self-determined and successful future because she, like the mighty Yangzi, had fought against all obstructions of tradition and ignorance and finally also managed to flow out into the Pacific Ocean (Chen n.d., 189) and freedom (albeit on the S.S. China), a young Chinese girl celebrating her new-found autonomy, even though, and with hindsight, the heteronomous nature of her project is clear: the very identity that she wished to forge for herself was predicated on an idea antithetical to traditional Chinese views of women including, as it did, free movement in public space, international travel, education, a career and authority. Her autobiography records the success of her project:

> I was thirteen years old, a year in which I discovered myself, so to speak, and started on a journey of my own choice. It was found out later on that this journey was full of dangerous rapids, of inaccessible mountain paths, and of a thousand and one perils; yet it was a journey of my own choice, and through thick and thin, through sunshine and rain, I have stuck to it; with a conscious mind and a willing heart even till this day. (Chen n.d., 47)

The similarities with the difficult journey of the Yangzi River are impossible to ignore. And, like the Yangzi, Chen is saying "What I am is proof of my struggle with those mountains" (Chen n.d., 2).[23] Writing in the late 1920s or early 1930s, Chen here is authorizing herself, making of herself a success. Her journey had taken her out of Chinese territory; she had become a woman of the world with a message for the future of her country. It was a form of self-colonization; her life, at least her understanding and interpretation of it, was predicated on Western ideals—self-determination, female equality and independence. She was abandoning the past's organizing principles of personal and politico-social life and relating to a "global" scheme of events.[24]

Parallel to this readiness for self-colonization, this self-created space for development that entailed the devaluing of local Chinese ideals in favor of a new frame of reference, both the American and the Chinese governments provided physical and intellectual spaces that enabled the colonization of minds. One possibility was created by the Boxer Indemnity Fund. This fund, formally agreed upon in 1908, was to provide a generation of young and Western-oriented scholars with degrees from renowned American universities, and their first-hand knowledge of life outside China and of scholarly activity quite different from the traditional Chinese curriculum. Political leaders in China resisted the attempt of President

[22] For the text in Chinese, see (Chen 2004, 1–3). For Chen's own version of the text in English, see (Chen n.d., 1–4).

[23] For the Chinese text, see (Chen 2004, 1).

[24] The universal importance of the self-determined individual had been underscored, for instance, through the popularity and the frequent translation of Samuel Smiles' *Self-Help* of 1859. See (Gimpel 2001, 127–128).

Roosevelt's government to impose the condition that the indemnity funds be allocated purely for educational activities. They sensed that this was an all-out attack on Chinese values, an attempt to further American political and economic efforts in China and create an educated class indebted to American society and open to American demands. As the president of the University of Illinois put it in a memorandum at the time, the educational use of the funds would lead to "the intellectual and spiritual domination of its [China's] leaders." The American Third Assistant Secretary of State, Huntington Wilson, commented in 1907 that the return of the indemnity funds "should be used to make China do some of the things we want. Otherwise I feel her gratitude would be quite empty."[25] Thus it is clear that the return of these funds, the amount of which had, from the beginning, been purposely wrongly calculated by the American government,[26] although still celebrated (as was certainly intended) in many a history textbook as a generous act of the United States towards China, was a calculated act of aggression, an attempt at intellectual colonization and control. Of course, it offered a broadening of mental and intellectual horizons positively wished for by a good number of young Chinese men and women at the time, but it also led to a situation where young men and women could no longer conceive of solutions to Chinese problems that could be taken from within their own culture.

Ironically enough, other scholarships for American universities were available through Chinese government grants, many of which appear to have been financed by funds dedicated to those who had contributed to the 1911 "revolution" and were to be trained as experts in various field. These government grants financed the foreign education of Chen's husband-to-be and close associate, Ren Hongjun (1886–1961).[27] Ren travelled to America, studied chemistry and was central in setting up the Science Society there.[28] He later returned to China to occupy positions vital to the development of scientific research and education. The Boxer Indemnity Fund paid for Chen Hengzhe's long wished-for "modern education." Not only did she subsequently become the first female professor of Western history at the prestigious Beijing University in 1920, she also compiled textbooks on Western history for the new national school system, textbooks that incorporated the scientific spirit her husband also ardently promoted.

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[25]Both quotations are taken from (Hunt 1972). The quotations are on p. 550 and p. 549 respectively.

[26]See (Hunt 1972) for a detailed discussion of the negotiations and the background to the Boxer Indemnity Fund remission.

[27]For Ren's description of the problems involved in getting the grant, see (Fan and Zhang 2002, 712–713).

[28]The nine founding members included seven Boxer and two non-Boxer fellows (Ren Hongjun and Yang Xingfo).

17.3 The Influences on Writing

Chen's history textbooks were commissioned for a series published by the powerful Commercial Press of Shanghai under the auspices of another ex-student in the United States, He Bingsong (1890–1946)[29] and at the invitation of the even weightier scholar, publisher and editor Wang Yunwu (1888–1979).[30] He Bingsong's career illustrates well the powerful networks that had been built up between the students in America and how they continued to sit at the center of knowledge dissemination when they returned to China. After returning home in 1917, he was, among other things, inspector of schools in Zhejiang province, professor of history at Beijing University, head of the English department at Beijing Higher Normal School. In 1924 he headed the committee for the history sections of the Commercial Press's encyclopaedia. From 1927 he was responsible for the influential education journal *Jiaoyu zazhi*. Chen herself was also benefitting from these close networks: Cai Yuanpei had offered her the job at Beijing University. Cai had been the Minister of Education in the early years of the Republic and was now head of the nation's leading university. He had worked and spoken with Chen's husband prior to Ren Hongjun's period of study in the United States.[31]

On her arrival back in China then in 1920, Chen, like others, was thoroughly ensconced in the institutions of change. We cannot reconstruct her lectures at Peking University, but we do still have two of her important contributions to a new understanding and dissemination of the course of history. On the one hand there is her two-volume *History of the West* (*Xiyang shi*) of 1924 and 1926 respectively, the first such publication by a Chinese historian and covering the history of the West from prehistory to the First World War; on the other we still have her *Short History of the European Renaissance* (*Ouzhou wenyi fuxing xiaoshi*) of 1930.[32]

In the original foreword to her *History of the West*, Chen made it clear from the beginning that her task as an historian was to provide explanations and to improve the materials available in Chinese for the study of Western history. In her "Introductory Remarks" to the books, she elaborated a little:

> Even if this is a textbook for higher middle schools, the author's aim is also to provide general knowledge of Western history for all people.

She wished "to train the reader's ability to analyze all kinds of phenomena in contemporary society."[33] Finally her main aim was to "aid young people in developing

[29]See (Wang 2001, 70–73).
[30]See the Foreword to *History of the West* in (Chen 2007, 3). For more information on Wang Yunwu, see (Boorman 1967, vol. III, 400–402).
[31]See Ren Hongjun's autobiographical sketch in (Fan and Zhang 2002, 712).
[32]Chen's *History of the West* has recently been republished in one volume (Chen 2007). The *Short History of the European Renaissance* (Chen 1930) has not been republished. For the present paper I have used a reprint of 1930 published in the series *Wanyou wenku* (Universal library) edited by Wang Yunwu. The author's preface to the text is dated 14th year of the Republic, i.e. 1925.
[33]See (Chen 2007, 3, 5).

an international perspective so as to reduce misunderstandings among people and increase their comprehension of each other."[34] In other words, her *History of the West* aimed to take students and general readers out into the world and to guide their understanding of it. Globalization—in the present sense of the inclusion of China in the world, of making China into a (respected) part of the globe—lies at the heart of her agenda. She underscored this in the closing words of her *History of the West*, and it is here that science, history, global inclusion and world development go hand in hand. In her understanding of the history of "cultural Europe," a term that includes "Europeanized America,"[35] the greatest effect of the development of science since the Renaissance had been the globalization (literally the "worldization" *shijiehua*) of European history, making European culture the common property of the world and enabling modern culture (*jindai de wenhua*) to open up completely new terrain (*xin xingshi*).[36] Here "modern culture" would appear to be synonymous with the culture emanating from the trajectory of Western history. She does not ignore the fact that both politics and capital have been able to misuse this phenomenon in the pursuit of selfish interest in the form of nationalism and imperialism, which, as she had insisted time and again in the course of her *History of the West*, ultimately lead to war, but she still preaches internationalism (*guoji zhuyi*), which would culminate in mutual understanding in the world and a time when each nation's culture would become the common property of the world. And, she warns, it will be the fight between nationalism and internationalism that will seal the fate of mankind in the future.[37] Global inclusion in her day involved the spread of knowledge of Western history; in the future, and in the form of internationalism, it would include an understanding of the cultures of the world.

It was clearly her intention to make sure that Chinese readers were aware of this "common property of the world" that constituted "modern culture" so that they could gauge the workings of the contemporary Chinese situation. It is also clear that, for her, the history of the world hinged on the important era of the European Renaissance,[38] and it is in her short fifty-page discussion and introduction of the European Renaissance of 1930 that we find most clearly expressed the principles by which she believed history "worked" and how China could align itself with these principles and become a part of "world history." Traditional Chinese views of history were to be devalued and replaced by evolutionary theory and the idea of progress in history. The past was now required to be linked with the

[34] See (Chen 2007, 6).

[35] See (Chen 2007, 7). In fact Chen had to admit that she had no room to include American history in her book. She planned an extra publication dealing with America.

[36] See (Chen 2007, 363).

[37] See (Chen 2007, 364).

[38] Renaissance, of course, was altogether an important term at the time. China was to be renewed and refurbished with a viable orthodoxy. See also Hu Shi's series of lectures on China from the 1930s collected under the title *The Chinese Renaissance*. The preface to the collection of lectures states that the title of the publication was "selected by him expressly to characterize the nature of the cultural transformation described" (Hu 1934, vii).

present. China had every possibility of travelling the same road to modernity as all other countries had taken.

Chen's *Short History of the European Renaissance* was published in 1930 by the Commercial Press. The choice of topic alone is telling. For Chen, the Renaissance was a return to order after the chaos of the Middle Ages; it was an entry into the light after a period of darkness; it was the emergence of man and his individuality, a turning away from the other-worldly concerns of the past and a focus on the here and now. This process, starkly simplified here, can, she wrote, be a "shortcut to a new culture," one that ushers in, among other things, the seeds of a spirit of investigation, the development of textual criticism, the setting up of libraries and academies, the systematic reform of education and the rise of women scholars able to interact freely with men. These *were* the issues at the center of the Science Society and its members who were worried that the "force of science" might not be "enough to sweep away the evil spirit that spreads all over the country." It underscored the contemporary issues that occupied these individuals as students and as professionals: women's emancipation and professions, the individual and his/ her ability (given the right attitude to life) to create his/ her own destiny, textual correctness in content and form, reform of educational curricula and the provision of information to the general public. In other words, this was political and social reform hand in hand with new frames of reference.

Not only the book's choice of topics reflects the concerns of those wishing to change the thought patterns of their fellow countrymen; the principles framing the interpretation of history reflect the way in which global trends could be brought to China, how the "common property of the world" was to be understood. On numerous occasions in the text, Chen introduces her readers to what, for the sake of simplification, I shall call universal "laws of history." These suggest to the reader that the developments she has traced through European history are applicable to other places (i.e. China). Thus, for instance, a new, modern culture "naturally" grew out of a scholarly reconsideration of one's own ancient culture. As she put it, "very soon new sprouts begin to form on old roots, and the new is ushered in" and, she added, this was a "common phenomenon" when a new culture is born as long as one rejects the *mode of thinking* that had ruled the past.

Another "natural law" illustrated through the Renaissance, according to Chen, was the revival of the true human spirit. Human reason, she explained, was a faculty that may be stymied for a while, but cannot be kept down forever. It was, she asserts in complete agreement with Cai Yuanpei, the spirit that rejected the superstition with which religion had (mis)guided humanity in the past. Finally, in the conclusion to her text, she summarized three ages in the life of any important historical development. In Chen's words, these are "the age of budding; the age of blossoming; the age of decline." What we have here is something simple that students can learn and something that they can apply to all events and developments in history. And China, coming out of the dark warlord period, could only be seen as positioned on the threshold of "the age of budding"!

The impression of a rule underlying historical and national development is further confirmed if we take into consideration the language in which Chen very often couches her descriptions and explanations. It is the language of the natural sciences and of the inevitability of seasonal change and growth and decline. She likens historical phenomena to the natural growth of sprouts, to the blossoming of trees, to the ripening of fruit and the falling of leaves, all at the right season. It is an affirmation of the complementary trajectories of the natural world and its inhabitants. Here, it is true, she is utilizing a common discourse in the writing of Chinese history, but as Arthur Wright has observed in connection with traditional Chinese views of history:

> On the surface this is a life-cycle analogy: polities, like men, have their periods of birth, growth, maturity, senescence, and death. Yet these successive phases were never seen as the product of natural law or blind fate. The dynamic behind them was moral and the lessons to be drawn from the study of dynastic rise and fall were moral lessons. (Wright 1965, 3)

Although we cannot exclude a certain moral component to Chen's historiography (she was preaching against war), her natural analogies, despite their classical roots, entail both reference to scientific findings and research and progression towards a new and improved human condition: internationalism and peace.[39] It can hardly surprise us that old and new discourse merge in this transitional era. Chen's text, however, was conceived of as new and was certainly in line with the recent discussions on a new study of history that had been taking place at Beijing University.[40] The text itself is written in a clear, non-classical language with modern punctuation and with footnotes.

This is an evolutionist history, if you will, in that it believes in the possibility of progress to a better world, even while it fears that the baser human instincts could gain the upper hand through war and exploitation. Evolutionary theory, something one might well term a widespread virus at the time, was one of the governing principles of her history writing and of the efforts of her natural scientist colleagues. It also influenced the manner in which she and her colleagues envisaged the cementing of the path to global inclusion and strength for China: ideas and institutions that had (apparently) been instrumental and necessary in the creation of strong nations throughout the world (scientific societies, scholarly and popular journals, publishing houses, libraries, national schools and universities, etc.) figured prominently in all their efforts and their plans for strengthening their country through a change of mental paradigm. The new (non-Chinese) study and analysis of history could illustrate general principles of global developments and aid in gearing the minds of China's youth to a different developmental trajectory

[39] References to scientific research and its results are frequent particularly in Chen's *History of the West*.

[40] For a discussion of the debates, see (Sang 2008, 134–136).

in their country. Science could give them the tools for implementing the required changes, and a recognition of their individual capacities—that the new scientific view of life would provide—would empower them mentally for the tasks.

But it was not only in her history texts that universal principles were incorporated and illustrated. As we have seen, her autobiography made it clear that the modern individual took on active responsibility for his or her own life (*zaoming*) and this principle also underlies her fable "The Grand Canal and the Yangzi River." It is recognizable also in the biographies she includes in her prose works. Just as the individual statement had taken on more significance through the use of quotation marks, individual lives incorporating the new universally applicable orthodoxy of success were now also considered important. In 1930 Hu Shi could write that "biography is the least developed branch of Chinese literature,"[41] but it was nothing new to write biographies of positive or negative historical figures. Chinese dynastic histories regularly included them. However, as noted many years ago, traditionally "[t]he ultimate purpose of biography was to instruct officials in orthodoxy, not to present rounded portraits of fallible human beings" (Boorman 1962, 453). This pattern was changed in the early twentieth century when the emphasis was placed on "the development of individual potential as a valid end in itself" (Boorman 1962, 454). In other words, the individual was being instructed in global orthodoxy. The significance of lives was calibrated differently; the exemplars and their target groups had changed, even though the mechanisms had not! Particular interest was shown in foreigners who were "founders of new nations or new 'isms' " as well as in revolutionary Chinese leaders of the "modern" kind.[42]

Chen Hengzhe's collected prose contains biographies of a number of exceptional women: Madame Curie; Jane Adams; a biography of her aunt whose personal strength and industry were a source of inspiration to her; her own autobiography; Abelard and Eloise; Wilfrid Wilson Gibson; Dante and Petrarch.[43] Strange bedfellows, one might believe, but they all share characteristics that she and her fellow scholars, educators and scientists emphasized: a strong will, a spirit of inquiry, a close connection with the real world, humanism and poetry.[44]

Chen's history books and some of her prose were aimed to take students and general readers out into the world; but her aim was also to bring the world to an understanding of China. This aspect of her globalizing activities, one that resonates with her desire for internationalism and recognition of all the cultures of the world, can only be mentioned very briefly here, but she and her associates not only presented and represented the global for a Chinese audience; they also

[41] Cited in (Howard 1962, 465).
[42] See (Howard 1962, 467).
[43] See (Chen 1995, 275–363).
[44] Almost all of the individuals discussed here wrote and published poetry themselves. Poetry, and in particular poetry in the vernacular, was also a central issue in reforming the nation. Hu Shi conducted the first experiments in vernacular poetry and Chen Hengzhe has been credited as having written the first Chinese short story in the vernacular. For a discussion of the "literary revolution," see (Chow 1960, 269–288) and *passim*. See also (Idema and Haft 1997, 259–266).

presented and represented China in the global arena. On four occasions between 1927 and 1933, she represented China at the meetings of the Institute of Pacific Relations, an organization that dated back to 1919.[45] One author chronicling the institute's activities in fact mentions that a volume of essays edited by Chen after the roundtable meeting in Kyoto in 1929, the *Symposium on Chinese Culture* (Zen 1931),[46] was still being used as a university text in America in the 1980s! (Hooper 1988, 106) Moreover, the contributors to the book read very much like a Who's Who of the Science Society and of students who had studied abroad in America or Britain. Thus Hu Shi wrote on religion, philosophy and literature, Ren Hongjun on science. Bing Zhi contributed a chapter on biological science. The book ends with Chen Hengzhe's "Summary of China's Cultural Problems." As the detailed list of contributors at the beginning shows, all of them occupied high positions in either government or education.

17.4 Conclusions

Chen Hengzhe and her associates were to become the national representatives of their new global associations and ideas. They were to become professors at prestigious universities and start new university departments and research centers, strengthening the fabric of the nation and strengthening China's national standing in the global arena. It was their texts that explained the world to China and China to the world and they were leaders in almost all the disciplines of a university system that no longer concentrated on the canonical texts of a central tradition. They had relegated that tradition to the sphere of the old. They had changed its forms of organization, its contents, its modes of linguistic presentation and manner of writing. They could do this at least until 1949 because in theory, and in partial practice, there was a developing system of reform at almost all levels of society. This was a national system also predicated on ideas perceived as universally relevant to good governance: a democratic parliamentary system. The demise, or severe restriction, of their influence was due not so much to the Japanese invasion of China or the corruption and incompetence of the Nationalist government, but to a changed regime after 1949.

All of these individuals were, to greater and lesser degrees, prone to the "intellectual and spiritual domination" so clearly targeted by educational and political circles in America, but none of them would have been such an enthusiastic victim of this domination if the historical situation of China had been a different one. Chinese intellectuals, in between orthodoxies, were caught up in the pursuit of solutions to the pressing problems of their country. They had been humiliated by the international community. Now they sought ways for themselves and their countrymen to join that same community. Karl Marx is much quoted as saying

[45] For a fascinating summary of the history and the significance of this Institute, see (Hooper 1988, 98–121).

[46] The book was originally published in 1931.

that shame is a revolutionary sentiment,[47] and it would not seem to be an exaggeration to say that what Chen Hengzhe and her associates were doing had all the makings of a revolutionary project: the changes in self-perception and self-definition that were to ensue through their work and their writing were intended to change and have changed China for good. The concepts and ideas they took to China have, indeed, had what Walter Benjamin termed an "afterlife,"[48] an existence and interpretation that may be quite separate from their origins and that depends on the perceived needs of the culture processing them at any given historical moment. Traditional (local) paradigms of national organization at all levels were devalued and replaced by international/global ideas and institutions. The individual gained a higher status (at least until 1949); the idea of science as a universally valid principle never left China again; universities on Western models became the norm and their curricula replaced Chinese learning with "universal" knowledge. In a post-colonial world it is hard not to look askance at the trajectories of individuals such as Chen Hengzhe; it is (or ought to be) difficult to swallow Chen's claims about the universality and global validity of the European experience and European knowledge. However, she and others like her inhabited an historically contingent space that made them into translated and translating individuals. It was a zone that made them the *object* of translation: they were no longer Chinese in the sense that Chinese intellectuals had been some fifty years earlier. Yet it was also a zone that made them the agents of an act of translating others. They were the victims of cultural imperialism; they were the protagonists in a process of self-colonization and the self-appointed and often self-important guides to a better future for China as a globally recognized player. They were the agents of a highly complex process of transculturation. They were on a mission to save the people, but often without consulting them, and they took their authority from the fact that they had studied abroad. This was their hubris. However, as Mao Zedong's contemporaneous and eventually stronger project of replacing local Chinese conditions with the universal ideological principles of socialism also shows, saviors are rarely modest!

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[47] Cited, for example, in Jean-Paul Sartre's "Preface" to Fanon's *Wretched of the Earth*, see http://www.marxists.org/reference/archive/sartre/1961/preface.htm.

[48] Benjamin was, of course, writing about translation in a more narrow sense, but his idea of the afterlife is equally applicable to the cultural translation project of bringing China into a global arena. See (Benjamin 2002, 16).

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Chapter 18
The Introduction of the European University System in Brazil

Oscar Abdounur and Adriana Cesar de Mattos

18.1 Introduction

This chapter reviews the introduction of the European university system in Brazil, focusing on the foundation and institutional history the University of São Paulo (USP). In particular, it will analyze the contemporary dispute over the teaching of integral and differential calculus. The general curriculum taught at USP was originally conceived to be introduced by European scholars, as it was believed that in this way the university spirit would be transmitted and established. In particular, the Italian mathematician Luigi Fantappiè (1901–1956) played an important role in the establishment of the calculus curriculum, both in the Faculty of Philosophy, Science and Language (FFLC) of the new university and at the Polytechnic School of São Paulo.

The Brazilian universities were founded astonishingly late. From colonial and imperial times up until the republican period of the early twentieth century, Brazil for a number of reasons in fact continued to resist the adoption of a university system. Unlike the Latin American countries that had been colonized by Spain, Brazil's first university was founded only in 1934 in the context of the defeat of the state of São Paulo in the Constitutionalist Revolution of 1932 against the central government of Getúlio Dornelles Vargas (1882–1954). Vargas was leader of the Revolution of 1930, which ended the old Republic, and from 1930 to 1945 was president of the Republic of Brazil.

At the center of this case study is the dispute between the USP University Council and the Collegium of the Polytechnic School over the Chair of Complements of Analytical Geometry, Elements of Nomography and Differential and Integral Calculus. In this dispute, the ongoing resistance to the founding of the university and the general context of the arrival of the European scholars become evident. More specifically, it will become clear that a principal reason for this dispute was a disagreement about the epistemological context of calculus instruction for engineers. This resulted in a specific approach being established in the early 1930s that emphasized axiomatic rigor.

The very idea of a university met with singular resistance in Brazil (Teixeira 1989). In colonial times, Portugal from as early as the sixteenth century had refused to allow the Jesuits to introduce a university to the colony. Since the time of José Bonifácio de Andrade Silva (1763–1838) and his struggle for Brazilian independence in the early 1820s, for over sixty years many projects for establishing universities had been proposed, but none of them were successful.

The situation did not improve even after the formation of the Republic in 1889. Resistance to the creation of a university in Brazil in fact had roots going back to the colonial period. Portugal's relations to its colonies followed a centralized model (Schwartzman 1979). This centralized model explains to some extent the strong contrast between the stable institutionalization of the Brazilian government during its independence process and what occurred in most other Latin American countries. Brazil's independence was atypical inasmuch as the other countries experienced wars and discontinuity of governments during their independence, whereas in Brazil there was no considerable turmoil during the passage from the colonial to the imperial period. This centralized tendency also explains why, contrary to popular belief, Brazil never had a Catholic church with indisputable authority and control, though the close relationships in Portugal between Church and State were transferred to the Brazilian colony and continued to exist in the Brazilian empire (Schwartzman 1979).

The following is based on the discussion in (Souza-Campos 1954) of the Brazilian education and scientific community up to the early 1950s. In addition, we have consulted the annual reports of the USP and Polytechnic School which comprise academic reports on seminars, conferences, talks and other documents mentioning the names of scholars who are today considered key players by historians of science in Brazil. We have furthermore consulted the minutes of the Polytechnic School Collegium and the University Council, which also contain substantial resources.

18.2 The Prehistory of the Creation of Universities in Brazil

In Brazil, both in colonial and in imperial times, government powers were able to resist or hinder the creation of a university, at least during the period when the government was strong enough. In most other Latin American countries, universities were founded much earlier during the Spanish colonial times, such as the National University of San Marcos in Lima, Peru (1551), Santo Tomas de Aquino University in Santo Domingo (1538) and the National University of Cordoba in Argentina (1613). In Brazil, the university made its first appearance only in 1934, that is, almost forty years after the proclamation of the republican regime in 1889.

The first constitution of the Brazilian Republic of 1891 was favorable to the creation of a university. Nevertheless, the initial period of the Republic experienced a strengthening of the anti-university tendencies. These were due to a preference for a pragmatic and positivist turn of higher education supposedly more suited to an ex-colony, emphasizing engineering, mining and agronomy. In a similar vein, humanities courses were considered to be futile and outdated since they seemed to be attached to the ecclesiastical model of the University of Coimbra.[1] Although the Brazilian positivists had taken an active role in the republican movement, they were against the implantation of a university system in Brazil and contributed to preventing its establishment. The positivist movement in Brazil originated around 1870 in the military. Positivist ideas were disseminated among the Brazilian soldiers who were influenced by Argentinian and Uruguayan soldiers during the Paraguayan war (1864–1870). Remarkably, although the positivist movement was representative of the republican movement in Brazil, some key ideas written into the first Brazilian constitution, such as the idea of creating university systems, were not shaped by them.

The text of the Brazilian constitution in fact supported liberal ideas whose essential political issues were in accordance with the political principles of the United States. A crucial characteristic of this text was the autonomy it conferred to the states of Brazil, for example, the Brazilian constitution equipped the new republic with a decentralized political model. A naive understanding of the institutionalization of the democratic republic could lead to the assumption that once this new political regime came into force, the pro-university faction would become strong enough to carry out the implementation of the university system. However, it took another forty years before this undertaking was actually realized, not least because of the political presence within the new regime of the Brazilian positivists.

At the beginning of the twentieth century, there was an increase in the number of vocational schools in Brazil, such as schools of engineering, agriculture and so forth. In 1900 there were thirteen such schools in the whole country: by 1920 the number had risen to thirty-four and by 1930 there were eighty-six. According to Sampaio (1991), this increase brought about the establishment of technical teaching with a scientific base, which depended on the development of a specifically scientific institution. This process contributed to the return of discussions about the implementation of the institution of university in Brazil.

The 1920s and 1930s also saw the emergence of scientific and artistic movements in Brazil, which strengthened the discussions in favor of the creation of a university. According to Schwartzman (1979), in 1922 the "Semana da Arte Moderna" in São Paulo enabled Brazil to produce its own art and therefore facilitated greater contact with the most original artistic movements of Europe. Also in the 1920s, the Academia Brasileira de Letras (Brazilian Academy of Letters) and the Associação Brasileira de Educação (Brazilian Association of Education) grasped the spirit of renewal of Brazilian science and education, initiating a strong movement to expand and modernize the educational system of Brazil at all levels. The Academia Brasileira de Ciências (Brazilian Academy of Science), created in 1917, encouraged publications in the journal *Revista Brasileira de Ciências* and promoted exchange with foreign scientists such as Émile Borel, Emil Grey, Henri Abraham, Henry Piéron, Albert Einstein, Paul Janet, Émile Marchouy and George Dumas, who visited Brazil in the 1920s.[2]

[1] See, also for the following, the discussion in (Sampaio 1991).
[2] See (Schwartzman 1979). See also (Kennefick 2012; Tiomno Tolmasquim 2012).

The Academia Brasileira de Letras is a Brazilian literary society founded at the end of the nineteenth century by a group of forty writers and poets inspired by the Académie Française. It is concerned with the national language of Brazil, Portuguese, and as well with Brazilian literature. The Academy is considered to be the most prestigious institution and authority in Brazil dedicated to the Portuguese language. The Associação Brasileira de Educação was founded in 1924. It encouraged the Movimento Reformador da Educação Pública (Reform Movement for Public Education), which demanded free public education. One of the most important leaders of this movement, the teacher, educator and Brazilian sociologist Fernando de Azevedo (1894–1974), wrote the manifesto of the pioneers of the new education movement in 1932. Its purpose was the reformulation of educational politics, comprising both basic and higher education. The former supported the democratization of education whereas the latter strongly supported the creation of a university in Brazil. Finally, the Academia Brasileira de Ciências was founded in 1916 in Rio de Janeiro and aimed to sponsor and disseminate science production in Brazil.

From 1927, a number of studies and initiatives were dedicated to secondary education and to the question of a Brazilian university. They were supported by the newspapers *O Estado de São Paulo* and *Jornal do Comércio*. Members of a commission established by the Associação Brasileira de Educação visited São Paulo, Bahia and the Minas Gerais states, and the section responsible for technical and higher education gathered the opinions of experts and professionals on a number of themes. These included the most suitable university model for Brazil, the question of whether research institutions should be included in the universities, which teaching methods should be used, as well as questions related to the professional status of university lecturers (Souza-Campos 1954). Between 1927 and 1929, a series of national conferences on education took place which dealt with themes such as the relationships between the universities and scientific research, the meaning of "university" and the problems in defining its role. Participants included prominemt Brazilian intellectuals such as Amoroso Costa, Tobias Moscoso and Theodoro Augusto Ramos (1895–1935). The main ideas underlying these conferences involved the separation of professional learning and scientific activities, the notion of free investigation and the concept of university autonomy (Schwartzman 1979). The ideal of creating a university in Brazil was based on the belief that the production and dissemination of knowledge through universities was crucial to a nation of global import (Souza-Campos 1954).

The first educational reform with national character was established in 1931 by the former minister of health and education Francisco Campos during the federal government of Getúlio Vargas. It established a layered curriculum with compulsory attendence and teaching at two levels: the first fundamental level would take five years and the additional level would take two years. The reform also required qualification at both of these levels in order to enter higher education. The educational reform of Francisco Campos was clearly orientated toward paralyzing the pro-university movement. The pro-university movement was supported instead by organized and autonomous scientific communities, as well as by the active sectors of the Academia Brasileira de Ciências and especially by liberal members of the Associação Brasileira de Educação (Schwartzman 1979).

At least two models can be identified that were considered as options in the dispute about what kind of university Brazil would adopt: the liberal model proposed by intellectuals linked to the Academia Brasileira de Ciências, and the model proposed by Francisco Campos's education reform. Despite the fact that the first university in Brazil, the USP, was based on the liberal model, from 1937 it was Francisco Campos's concept of a national university within a centralized system that predominated. Despite this outcome, the USP became the main academic institution in Brazil.

18.3 The Constitutionalist Revolution of 1932

Before we discuss in detail the creation of the USP we will first review the Constitutionalist Revolution which provides the main historical context for the creation of the first university in Brazil. The main political figure of this period was Getúlio Vargas, president of Brazil, first as dictator from 1930 to 1945, and then in a democratically elected term from 1951 until his suicide in 1954. His government was marked by nationalism, industrialization, political centralization and populism. Vargas widely supported workers' rights and was an anti-communist. In the context of the impact of the Great Depression on the Brazilian economy, Vargas came to power through a coup d'état in the Revolution of 1930, which marked the end of Brazil's oligarchic Old Republic (1889–1930). Regional leadership supported by the Armed Forces who were dissatisfied with São Paulo's political dominance backed Vargas, the defeated candidate in an electoral process that had been denounced as fraudulent, as was often the case in the Old Republic. Vargas successfully influenced the next presidential election and instituted an authoritarian regime in 1937 known as Estado Novo (New State), prolonging his hold on power. He transformed Brazil from an agricultural to an industrialized country, protecting domestic industries and sponsoring the necessary infrastructure. With the global rise of democracy in the aftermath of World War II, Vargas agreed to cede power in free elections, thus ending the dictatorship of the Vargas Era.

During the Constitutionalist Revolution of 1932, also known as the Paulista War, the population of the state of São Paulo rose up against the central government of Getúlio Vargas in fighting that lasted from 9 July to 4 October. The movement was triggered by local dissatisfaction with Vargas's disrespect of the autonomy of Brazilian states and demanded a new constitution for Brazil. Although the state of São Paulo was defeated, Vargas granted some of the main claims of the revolutionaries, such as the appointment of an elected non-military state governor and the decree for a new constitution in 1934. This new constitution, however, lasted only for a short period, since in 1937 Vargas closed the

National Congress and created another constitution that established the authoritarian regime, known as "Estado Novo." The Constitutionalist Revolution was the first major revolt against the government of Vargas and the last major armed conflict in the history of Brazil.

The revolution had been supported by São Paulo's bourgeoisie and demanded a democratic constitution for the republic of Brazil, as well as the administrative independence of the state of São Paulo. It had no longer been possible to reconcile the political elite of this state with Vargas's central government. Although the financial crises in São Paulo during this period may have played a role, the roots of discontent in this state stemmed mainly from the resentment and injured pride of its people (Hilton 1982, 28). Regarding the relative degree of autonomy that the states enjoyed before the 1930s, the Constitutionalist Revolution can be seen as a final echo of the old Republic. Traditional groups all aimed to regain control of state administration. This aim was much stronger than the antagonisms that divided the republicans and democratics and sufficed to unite them against the centralized regime of Vargas (Hilton 1982, 329). A new constitution would thus provide a way to regain the autonomy of the state. In the end, the inevitability of armed conflict derived from the fact that Vargas in 1930 did not hand over state leadership to a Paulista, that is, to a native of the state of São Paulo, who had been chosen by its people.

In May 1933, after the defeat of the revolutionaries, Armando de Salles Oliveira (1887–1945) was elected governor of São Paulo as part of a compromise between São Paulo and the central government. Had Vargas in November 1930 handed over the state of São Paulo to a prominent member of the democratic party linked to the cause of the Revolution, then the country would probably not have entered into civil war in July 1932 (Hilton 1982). More generally, after the Revolution Vargas conceded many of the demands that had caused unrest in 1930.

18.4 The Creation of the USP in the Context of the Constitutionalist Revolution of 1932

The creation of the USP resulted from Getúlio Vargas's acceptance of Armando Salles de Oliveira as leader of the government of São Paulo in the final negotiations with the leaders of the Revolution (Hilton 1982). The university was created by official decree of the government of São Paulo on 25 January 1934. It was based on the liberal model, which was not the model proposed by the central government so tension between both institutions was inevitable. Several attempts to found universities in Brazil had been made before the creation of the USP, many of which remained mere concepts or paper decrees that never actually materialized. At the University of Rio de Janeiro, for example, the institutions of higher education were not under the administrative control of the university. In contrast, in the case of the USP, the higher education institutions involved did not retain their autonomy. The creation of the USP in 1934 can be considered as the most important undertaking in the history of science and education in Brazil. Its creation and development differed considerably from that of the other universities in Brazil (Schwartzman 1979).

The creation of the USP constituted a political, marketing and epistemological endeavor by a number of figures: the governor of São Paulo, Armando de Salles Oliveira; the owner of the newspaper *O Estado de São Paulo* Julio César Ferreira de Mesquita Filho (1892–1969); and by other Brazilian intellectuals. Mesquita Filho first studied in Europe, returning to Brazil to attend the School of Law of São Paulo, Largo de São Francisco. He began as a journalist in the evening edition of the *State*. Exiled for the first time after the defeat of the Constitutionalist Revolution, Mesquita Filho returned to São Paulo to create, together with de Salles, the USP. Mesquita Filho believed a university could provide Brazil with a new political and cultural elite. He had been one of the leaders of the Revolution and was convinced that the people of the state of São Paulo should be prepared to fight to defend their political rights (Hilton 1982). While not all of the people were similarly motivated, they were all convinced that to end the problems related to the hostility of the revolutionary regime installed by Vargas in 1930, sooner or later it would be necessary to take up arms. Another of the intellectuals involved in the creation of the university, Paulo Alfeu Junqueira Duarte (1899–1984), participated as leader of one of the more active clandestine groups, the so-called "núcleos de ação." Indeed, some civilians and military figures in Sao Paulo had been conspiring ever since the failed uprising in April 1931. Duarte was a biographer, poet and journalist. He was close to General Isidore, who by mid-1931 had secretly mobilized army officers. He also took part in the Constitutionalist Revolution and later held the Chair of Prehistory at the USP (Hilton 1982, 41; Silva 1997).

In 1934 Brazil was also entering the Industrial Revolution. The Constitutionalist Revolution had revealed the weaknesses of the military industries in Brazil (Hilton 1982). The delays and other difficulties experienced in attempts to buy materials abroad revealed the danger of external dependency. This led to a systematic effort in the post-war period to stimulate civil industries to contribute to the military. The main target in this move towards military autonomy was the industry of São Paulo, which had faced many difficult situations during the three dramatic months of the Constitutionalist Revolution.

In São Paulo, the group involved in the movement for the creation of a university was constituted by Theodoro Ramos, an engineer from the Polytechnic School, Julio de Mesquita Filho, Fernando de Azevedo, director of the Instrução Pública do Estado de São Paulo (Public Training Center for the State of São Paulo) and Paulo Duarte. Armando de Salles Oliveira put these names forward for the organizing committee charged with establishing the USP. Mesquita Filho was the president of this committee and Ramos charged with bringing European scholars to Brazil. Still in this context, an important undertaking assumed by Mesquita Filho and Duarte, together with Fernando de Azevedo was to establish the Faculty for Philosophy, Sciences and Languages which was to integrate all fields of knowledge and become a prestigious center for basic scientific research (Silva 1997). Several factors are responsible for the success of the USP. One of them is that the university inherited prestige from the School of Medicine, the School of Law and the Polytechnic School, all of which were integrated during its creation. Another important factor was the role of the Faculty of Philosophy, Sciences and Language, which did not come into being until the foundation of the USP.

18.5 The International Perspective in the Creation of the USP

Julio de Mesquita Filho affirmed in 1937 that only a radical reform of the educational apparatus in the country and the instauration of a strong educational policy could avoid chaos in Brazil. The goal was to prepare an "intellectual elite," who would lead Brazilian society to progress, happiness and freedom. Comparing the situation of Brazil with that of other countries that had suffered a major defeat, Mesquita Filho commented:

> At the end of the Revolution of 1932, we had the feeling that destiny would have put São Paulo in the same condition as Germany after Jena, Japan after the bombing by the North American navy, and France after Sedan. The history of these countries would suggest the medicines for our evils. We had experienced the terrible adventures provoked, on the one hand, by the ignorance and incompetence of those who before 1930 had decided on the destiny of our state and of our nation, and on the other hand, by the emptiness and the pretension of the revolution of October 1930. Four years of close contact with the leaders of the two tendencies convinced us that the problem of Brazil was mainly a question of culture. Thus is the importance of our university and also of the Faculty of Sciences and Letters (FFCL).[3]

The new university would be public and free of religious influence; it would be an integrated institution and not a group of isolated schools. At its center would be the Faculty of Philosophy, Sciences and Language, with lectures given by Europeans. Research activities would be led by a full-time team working with the most modern forms of science. Practical work would be left to the professional schools. The university would have administrative and academic autonomy and create a new elite, who would assume the leadership of the country and make São Paulo a leading state in the federation (Schwartzman 1979).

According to Teixeira (1968), in the 1930s Brazilian intellectuals and politicians believed that the creation of a faculty for philosophy, sciences and language would mean the inclusion of disciplines not necessarily associated with a professional vocation. The main purpose of the USP was to offer broad instruction

[3] This is part of the speech delivered by de Mesquita Filho on the occasion of the first students' graduation from the FFCL in 1937, see (Mesquita Filho 1939).

comprising courses on scientific subjects, literature, arts, philosophy and other subjects. In order to succeed in creating a university with such features, Brazilian intellectuals and politicians believed it was necessary to bring in delegations of European scholars, whose experience would encourage the development of a university spirit among the students.

In 1934 Theodoro Augusto Ramos was commissioned by the governor of São Paulo, Armando de Salles Oliveira, to head a delegation to the academies of Europe to hire researchers for the newly created Faculty of Philosophy, Science and Languages at USP. Ramos studied civil engineering at the Polytechnic School of Rio de Janeiro (1917) before obtaining his Ph.D. in physics and mathematics. He was then elected member of the Brazilian Society of Sciences (1918) and appointed Chair of the Polytechnic School of São Paulo (1922). The delegation to Europe also comprised the faculty chairs Georges Dumas, Paul Rivet (1876–1958) and Pierre-Marie-Felix Janet (1859–1947). Rivet was a French ethnologist, and Janet a French neurologist and psychologist.

Around 1934 many Brazilian intellectuals were influenced by Europe and America, whether they had studied at foreign universities or not. For example, Cândido Lima da Silva Dias (1913–1998) was influenced by the famous group of French mathematicians around Nicolas Bourbaki. He became the first director of the Institute of Mathematics and Statistics, IME/USP (Silva Dias 1994). He began his studies at the Ecole Polytechnique in 1932, but moved to the newly created subsection of mathematics at USP in 1934. His first academic paper in 1941 on the theory of analytic functions inspired him to pursue a teaching career, to which he devoted himself for fifty-four years. From 1948 to 1949 he went to the United States, more specifically to Harvard, Princeton and Chicago, the three main centers of mathematics at that time. He dedicated his life to stimulating scientific research in mathematics and to the training of new researchers, as well as the dissemination and improvement of mathematical culture in the country.

Although the theoretical knowledge of European scholars was not necessarily the same as that of Brazilian scholars, all of these intellectuals shared the ideology of a university based on "general culture," as manifested in the Faculty of Philosophy, Sciences and Language. Naturally, Armando de Salles Oliveira and Julio de Mesquita Filho expected European scholars to support this ideology and worked to instill this in their Brazilian students. According to Petijean, the organizing committee agreed not to invite Germans or Italians to the chairs of humanities in order to prevent their nationalist influence. They invited French scholars to teach "human sciences," such as sociology and history, and Italians and Germans to teach mathematics, physics and chemistry (Petijean 1996).

In 1934, Europe was economically and politically unstable, a situation that was favorable to Brazil in its foundation of the USP. Some European intellectuals were eager to leave Europe, a situation that facilitated negotiations with these scholars. Many communist intellectuals moved to the American continent, but also nationalist intellectuals who went to spread their ideas, as was the case with Fantappiè (Petijean 1996).

18.6 The Internal Structure of the USP and the Controversial Status of Mathematics

As mentioned above, the creation of the USP in 1934 led to a loss of autonomy for the institutions of higher education in the state of São Paulo. The directors of the academic institutions were then appointed by the governer of São Paulo, Armando de Salles Oliveira. The consequence of this loss of autonomy was the enforcement of ideals that did not correspond to the tradition of the independent and vocational schools, such as the schools of medicine, law and of polytechnic engineering, which had been founded during the times of the empire (Teixeira 1968).

The governer de Salles appointed the rector as well as the directors of the institutions of higher education, including the director of the Polytechnic School. The engineer Fonseca Telles was appointed director by the government in absence of the Polytechnic School Collegium (USP 1935). The Polytechnic School lost its self-administration, evidenced by the fact that the new director oversaw the school's supervisory body (USP 1935).

The case of the Polytechnic illustrates the controversial status that the introduction of European ideals had for the university. The ideal of the university based on the Faculty of Philosophy as integrating all areas was evidently not shared by everyone. That a mathematician rather than an engineer should occupy the chair of mathematics at this school was the expression of the idea that subjects of "general culture" should be taught by lecturers of the Faculty of Philosophy, or more precisely, the Faculty of Philosophy, Science and Language. For the engineers of the Polytechnic School, however, a mathematician was unacceptable, since a mathematician was not considered capable of teaching the approach that engineers found necessary for their purposes (USP 1935). A mathematician would present this knowledge, prioritizing axiomatic rigor, at the expense of immediate applications, an approach typical of those who graduated in courses of "general culture" (USP 1935).

The majority of the advisers of the Polytechnic School Collegium did not accept the proposal to appoint the mathematician Luigi Fantappiè, however, arguing that mathematics for engineers should be taught by engineers (USP 1935). Fantappiè was born in Viterbo, Italy. He began his studies at the Scuola Normale Superiore in Pisa in 1918 and graduated with a doctorate in 1922. After studying from 1922 to 1924 at various universities abroad, he worked in Rome and Cagliari. In 1926 he was appointed Chair of Algebraic Analysis at the University of Florence; he then moved to Palermo to take up the Chair of Infinitesimal Analysis. He was invited by Theodoro Ramos to help set up the mathematics curriculum at the USP and also to assume the Chair of Complements of Analytical Geometry, Elements of Nomography and Differential and Integral Calculus at the Polytechnic School. Fantappiè returned to Italy in 1939 at the outbreak of World War II when he was offered the Chair of Higher Analysis at the University of Rome, a position he held for the rest of his life.[4] Fantappiè's appointment by Director Fonseca Telles was rejected by the Polytechnic School Collegium (USP 1935). Over a period of twenty years, this chair would be a matter of contention between those who ran the mathematics course at the FFCL and the Polytechnic School at the USP (Marafon 2001).

The examination held to fill the Chair of Complements of Analytical Geometry, Elements of Nomography and Differential and Integral Calculus took place in 1933. Even before 1934, one of the candidates, Omar Catunda, suggested there were irregularities in the exam and requested that the examination be investigated by the juridical advisor. This investigation set off a series of legal and political events that reinforced the authority of the university over the Polytechnic School. Omar Catunda was born in 1906 in Santos, Brazil. He studied at the Polytechnic School of São Paulo in 1930 and worked briefly as an engineer for the local government in Santos. In 1933 he took the examination for the Chair of Complements of Analytical Geometry, Elements of Nomography and Differential and Integral Calculus and was approved as a candidate of second rank. In 1934 he became the assistant to Luigi Fantappiè at the USP. In 1944 he took over the Chair of Analysis at the FFCL. He not only initiated many young people in the research in his field of functional analysis, but also played a central role in restructuring the teaching of mathematics analysis. In 1963, Catunda retired from the USP and assumed a position at the Federal University of Bahia, where he remained until his death in 1986.

18.7 Fantappiè and the Dispute Concerning the Chair of Calculus at the Polytechnic School

Up until 1934, to be a mathematician in Brazil meant being affiliated with a chair of mathematics at an engineering school since at that time no high-level mathematics courses existed; up until that time the teaching of mathematics was the sole responsibility of the engineering schools.

In 1934, with the creation of the USP, Italian mathematicians were invited to Brazil to collaborate in shaping the mathematics conceptions in the courses of the FFCL. In particular, as we have discussed, Fantappiè was invited to assume the mathematics chair at the Polytechnic School. This chair was established at the same time for the new USP and the old Polytechnic School, institutions represented by the University Council and the Collegium of the Polytechnic School, respectively.

Four names will be at the focus of this section, three of which will already be familiar to the reader: Fantappiè, Ramos, director of the FFCL, Omar Catunda,

[4]See http://www-history.mcs.st-and.ac.uk/Biographies/Fantappie.html.

and José Octavio Monteiro de Camargo. Camargo was a mechanical and electrical engineer who graduated from the Polytechnic School in 1922. Since he had ranked first, he was entitled to a scholarship to study abroad. While based in Brussels and Liège in Belgium, he also worked in Germany and Italy. Between 1928 and 1933 he was the Deputy Chair of Complements of Analytical Geometry and Elements of Nomography Differential and Integral Calculus at the Polytechnic School. In November 1933, he applied for the chair and was ranked in first place, but another candidate appealed the examination so that it was annulled in 1934. Camargo also appealed against this result and won the case by a decree of 18 June 1938. He became a member of the University Council in 1938 (USP 1938).

Fantappiè is regarded as one of those responsible for a change in the approach to teaching mathematics at the Polytechnic School and for how the mathematics curriculum at the FFCL was shaped. This turned out to be based on axiomatic rigor influenced in general by the Italian mathematicians, a claim commonly accepted by the historiography of the USP and presented, for instance, in interviews with the mathematicians from the FFCL, such as Cândido Lima:

> The presence of foreign teachers at the pioneer stage of the Faculty of Philosophy was crucial, important and refreshing. Fantappiè, for example, introduced in Brazil the mathematics courses, previously taught only in polytechnics and engineering schools, which had been restricted to the infinitesimal calculus. Fantappiè developed courses of an entirely different nature: group theory, continuous groups, number theory, differential forms applied to analysis, tensorial analysis. (Silva Dias 1994)

According to the interview by Cândido Lima da Silva Dias (1997), Ramos had the freedom and knowledge to choose Europeans to shape mathematics in the FFCL. Another testimony comes from Milton Vargas, born in Niterói in 1914. He studied at the Polytechnic School of São Paulo during the 1930s, graduating in 1938 as electrical engineer and in 1941 as a civil engineer. He made important contributions to the research field of ground mechanics and accepted a chair at the Polytechnic School of the USP in 1952. He received the title doctor honoris causa from the University of Rio de Janeiro and since 1988 has been emeritus doctor at the Polytechnic School of the USP, the highest honor ever granted to a lecturer at this institution. Milton Vargas emphasized the pivotal role of the new mathematics teaching:

> The success of these two basic courses: mathematics given by the Italians Luigi Fantappiè and Giacomo Albanese, and physics by the Italo-Russian Gleb Wataghin is explained by the higher didactical capacity of these excellent teachers and by the fact that they were aware that they were also teaching future engineers. The influence of this new approach to training engineers was remarkable. It occurred at precisely the time when the evolution of technology required higher mathematics and advanced physics to solve technological problems. Even today

> the engineering teaching at the Polytechnic of São Paulo cannot escape the echoes of that great revolution promoted by Fantappié, Albanese and Wataghin (Oliveira 2007, 20).

The minutes of the University Council evince no consensual opinion about Fantappiè's teaching at the Polytechnic School (USP 1935). Apart from this, the director of the Polytechnic School's decision to appoint Fantappiè to the Chair of Calculus was seen as an affront by most members of the Collegium of the Polytechnic School. This situation set off a dispute between the Collegium and the University Council, which led the Collegium to seek juridical review of the case. During the University Council meeting of 13 March 1935, the juridical advisor Abrahão Ribeiro was presented as a referee:

> [...] he recognizes the high value of the lecturer Fantappiè and thinks that to the Polytechnic School it would be more desirable to have a teacher who is purely professional and he does not see any advantage in high cultural education [general culture]. He quotes Professor Ammann from Karlsruhe to support this thesis: "In all the technical colleges, the first three or four semesters comprise mainly mathematics, mechanics, natural and economic sciences. We do not consider these to be science in themselves, as in the universities, but always from the viewpoint of their applications. For technical colleges, however, there is a great difficulty in the fact that teachers of these disciplines, most of whom come from universities, only rarely—if ever—can adapt themselves to the needs of the superior technical college. They teach in a very abstract way, without regard for technical applications. Mathematics cannot help but discourage the young students unless they can apply it on the basis of technical studies. Consequently it is an urgent need for superior technical schools to train mathematical engineers who are encouraged by the understanding of the technical problems to reveal to the young students the necessity and beauty of this auxiliary science. One could thus achieve very different results of mathematical studies. Thus it began that chairs for mathematics were entrusted to engineers, as has already been done almost universally with regard to the chairs for mechanics." (USP 1935)

This dispute is representative of a process which, in the twentieth century, occurred at most institutions of higher education where mathematics was taught as an auxiliary science. In our case, we have seen that mathematics at the Polytechnic School even became a matter of dispute in a legal and political sense. Who would be the better lecturer, Fantappiè, the mathematician, or Camargo, the mechanical and electrical engineer? Since the fundamentals of calculus would be taught according to the teacher's approach, it was a matter of contention rather than choosing the "right" candidate.

The detailed history of the appointment was extemely intricate and litigious. According to the minutes of the Polytechnic School Collegium (USP 1935) Jorge Americano argued, based on the Polytechnic School Statute:

> Since the Chair's replacement must be established in accordance with Article 112, Fantappiè cannot be hired to this chair because he is not the Chair of Calculus as well. In this case, it is the responsibility of the Polytechnic School Collegium to appoint a substitute, and the director's responsibility to implement this resolution according to the article mentioned above.

Jorge Americano remembered the important fact that the unoccupied chair depended on appeal, which, had this turned out in Otavio Camaro's favor, would have resulted in its immediate occupation by him. The previous occupation of the chair by a foreign lecturer, in this case Fantappiè, could have resulted in an embarassing situation. The University Council, however, approved the Fantappiè for the Chair of Calculus. According to Fernando de Azevedo's argument, this case could be regarded as a case of omission for this statute. In this situation the Council decided to vote. In a vote by the Committee on Legislation and Appeals, the decision was approved against the votes of the chairs Ricardo Gaspar Jr., Octavio Teixeira Mendes and Jorge Americano (USP 1935). Gaspar Ricardo Jr., a member of the University Council, declared that the decision had not taken the Polytechnic School Collegium into account. He considered this to be an act offensive to his own prestige, asserting that he would not subordinate himself to the deliberation of the University Council and that he would appeal to the competent authorities. After expressing his opinion he left the meeting (USP 1935).

Azevedo argued that the case of the appointment of the lecturer Fantappiè to the Chair of Calculus had already been resolved since it had been collectively accepted against the vote of Lucio Martins Rodrigues. Gaspar Ricardo advocated appointing the engineer José Monteiro de Camargo to the Chair of Calculus for the sake of fairness (USP 1935). Director Fonseca Telles refuted Ricardo Gaspar's argument stating that the school had a Committee of Inspectors that would be responsible for analyzing the appointment process in due time. He also criticized the opinion of Dr. Abrahão Ribeiro. Telles argued in favor of Fantappiè:

> If the Council established the statute, who would be better than the Council to interpret the statute? According to the spirit of the statute and of its legislators, in the case of a vacant chair it was not even necessary to bring the case to the Collegium [of the Polytechnic School]. The director brought the case to the Collegium in a spirit of liberty [democratic spirit] in order to avoid being accused of acting as a dictator. Due to the appointment made [Fantappiè], it was contrary to the statutory rules and he appealed to the University Council. (USP 1935)

Azevedo criticized Gaspar Ricardo's arguments:

> With regard to the doctrine held by Gaspar Ricardo concerning practical teaching being strictly professional in the colleges [institutes of higher education], he disagrees substantially. It seems wrong to him. […] Application is the function of theory and can only be good for the people in the context of the "general culture." He says that the issue of the abilities of Fantappiè and Monteiro de Camargo as teachers cannot be discussed by the University Council. (USP 1935)

Indeed, the Polytechnic School Collegiate was subordinated to the University Council:

> The Chancellor of the USP remarks that the Polytechnic School Collegium is obliged to accept the deliberations of the University Council and that, by law, it not only has a duty, but also the right to be represented. (USP 1935)

Azevedo proposed a special committee to try to broker the peace between the Polytechnic School Collegium and the University Council and to require the governor to solve the matter of the 1933 examination for the Chair of Calculus in which Camargo was involved. The meeting was adjourned after voting on the measure, which was defeated by six to four (USP 1935).

The appointment of Fantappiè was in agreement with the general aims of the intellectuals, politicians and journalists who favored the creation of a university involving European scholars. According to Oliveira (2007), Fantappiè personified the formalist view. The formalist movement was a major current in the mathematical community of the twentieth century. It was associated with a movement that began in the nineteenth century and is known today as the arithmetization of analysis. Oliveira (2007) suggests that the influence of Fantappiè was felt mainly in the mathematics course at the USP. After 1938 the Polytechnic School acquired the teaching status it had enjoyed before 1934, since José Monteiro de Camargo ultimately took over the Chair of Complements of Analytical Geometry, Elements of Nomography and Differential and Integral Calculus by order of the governor Adhemar Pereira de Barros (1901–1969). In other words, the final match was won by the engineer José Monteiro de Camargo in 1938. As we have seen above, he was ranked first in the 1933 examination, but this was annulled in 1934 by the juridical advisor of the USP after an appeal by Omar Catunda. Fantappiè and other European scholars, on the other hand, collaborated to create the Faculty of Philosophy, Sciences and Language, and with it to concretize the ideal of the university.

18.8 The Shift of the Mathematics Curriculum

In 1934 the official calculus curriculum of the Polytechnic School was shaped by Rodolpho Baptista de San Thiago (1870–1933), who was an engineer at the Polytechnic and Chair of Calculus until 1933 before his replacement by Luigi Fantappiè in 1934 (Oliveira 2003). He had been responsible for analytical geometry and infinitesimal calculus at the Polytechnic School since 1904. His lecture manuscripts are entitled "infinitesimal calculus" and in them he presented notions of function and continuity, in addition to explanations about the special methods of infinitesimal analysis: the method of exhaustion applied by Archimedes; Leibniz's method of the infinitesimal; Newton's method of the first and last ratios; and Lagrange's method of derivatives. The 1930 syllabus for the differential and integral method, published in the 1932 Annual Report of the Polytechnic School, shows an introduction to series, citing the convergence and expansions of the logarithm and exponential series functions. This agenda was used to introduce Lagrange's method, which appears in the second introductory topic. The methods of Newton and Leibnitz are also included in this program.[5]

This raises the question of what Fantappiè taught when he held this chair. According to Oliveira (2007), Fantappiè was responsible for a change in the foundations of the calculus course, for which he adopted the textbook by Severi (1933).[6] The way that Fantappiè taught mathematics induced a different kind of involvement in the students than the instruction by de San Thiago (Silva Dias 1994). The students of the newly established Mathematics Department and the students of the Polytechnic School were the first to benefit from this teaching.

It was the idea of limits as the foundation of calculus that characterized the change conceived by Fantappiè. Severi's book defined limits through the Weierstrass conception, i.e., using the ε-δ method. Severi's concept of the real number, built by means of Dedekind cuts (Oliveira 2007), endowed the teaching of calculus with a formalist approach. From the point of view of the history of mathematics in Brazil, the arrival of the Italians contributed to the consolidation of the axiomatic rigor as the abstract approach according to which calculus should be taught in Brazil. This approach had already been introduced by Ramos, who was responsible for the choice of mathematicians and physicists to be invited to the USP.

The concepts presented in differential and integral calculus now acquired a characterization that no longer depended on movement or time. For example, the geometrical or physical characterization of the derivative was substituted by the corresponding definition involving the limit of a function, that is: For all ε and δ exists such that, if $0 < | x - a | < \delta$ then $0 < | f(x) - L | < \varepsilon$, and continuity according to the Weierstrassean conception. In the twentieth century, infinitesimal

[5]San Thiago's syllabus *Curso de Cálculo de Rodolpho Baptista de San Thiago* (1904). Archives of the Polytechnic School of São Paulo (Oliveira 2003).

[6]For biographical details of Severi, see http://www-history.mcs.st-and.ac.uk/Biographies/Severi.html.

analysis (Robinson 1996) and calculus occupied a place only in the philosophy of mathematics. Both mathematics production and mathematics teaching saw their fundamentals dictated by axiomatic rigor.

According to Oliveira (2007) other important aspects of Severi's text include the weight given to discrete mathematics, with algebra comprising half of the text besides calculus, and the fact that historical dates are included for all subjects treated.

In San Thiago's texts the definition of the limit is as follows:

> The definition of infinitesimal analysis derives from the fact that the method of Leibniz is the one more usually accepted. Before introducing the method of Leibniz, let us give a notion of the old method, which was the foundation of differential calculus. It is called the *limit* of a quantity, a fixed quantity which a variable approaches without ever reaching it. The difference between the fixed limit and the variable can become smaller than any given quantity. If we suppose a circumference and a polygon inscribed in it, and if we always duplicate the number of sides, the polygon will approach the circumference and the latter will be the limit of the former.[7]

According to Oliveira (2007), Severi's book was adopted within a year of San Thiago's replacement by Fantappiè at the Polytechnic School and used for several years in the mathematics and physics courses of the FFCL—USP. In 1939, after writing the "The Course of Mathematical Analysis," Fantappiè returned to Italy. This text had the same theoretical foundation as Severi's book and was edited by Professor Omar Catunda, his assistant at the time. According to Silva Dias (1994) Fantappiè's lectures were given in Italian. The physicist Wataghin initially gave his lectures in Italian, and later in Portuguese.

An important role in supporting the shift of the mathematics curriculum was also played by the creation of the Mathematics Library:

> I remember well the foundation of the Mathematics Library. Fantappiè was very dedicated to this initiative. When he came from Italy, he brought many books and journal collections and donated them to the library, marking the beginning of the Mathematics Library. He also included some books from the Polytechnic School. When Fantappiè returned to Italy in 1939, our library was already appreciable and has grown ever since. As a result of the university reform of 1970, all books related to this subject were brought together into the Library of the Institute of Mathematics, consequently generating a reasonable collection if compared to the libraries of North America and Europe

[7]San Thiago's syllabus. Curso de Cálculo de Rodolpho Baptista de San Thiago (1904). Archives of the Polytechnic School of São Paulo (Oliveira 2003).

universities. What few people know, however, is that the initial impetus for the formation of this library was given by Luigi Fantappiè. (Silva Dias 1994)

18.9 Conclusions

The conflict concerning mathematics teaching at the newly founded USP was played out on several levels: it was a conflict between different conceptions of the university itself, including its role in society and its openness to foreign influences; an institutional conflict about administrative autonomy between the Polytechnic School Council and the University Council; a political conflict in the aftermath of the Constitutionalist Revolution; a dispute concerning the didactic value of mathematical axiomatic rigor versus the merits of a more intuitive understanding of infinitesimal calculus; a struggle over the role of tradition; and the relation between fundamental and applied science, between mathematics and engineering. The conflict unfolded in terms of an intellectual dispute, of academic politics, but also decisively involved juridical litigation. In the history we have reconstructed, all of these dimensions were intertwined and thus all shaped the final outcome.

The final outcome, on the one hand, was the fact that José Monteiro de Camargo took over the Chair of Calculus in 1938, and this apparently represented a victory of tradition over modernity. From another perspective, however, the final outcome was Luigi Fantappiè's long-lasting influence on future generations of students, despite the relatively short duration of his stay in Brazil.

Both "final outcomes" were the consequence of both global and local factors and of long-term historical developments. The theme of the university had been discussed in Brazil for over four centuries. When such an institution was finally established, it followed a by then almost universally accepted model, which included the then prevailing international trends for treating certain subjects, such as mathematical axiomatic rigor to mathematics. Local resistance against this international trend involved an intellectual debate about the nature of mathematics teaching, which could have been a starting point for the development of new didactic approaches that combined practical with rigorous aspects. Instead, however, the conflict, which had been ongoing in Europe since the nineteenth century, was settled by juridical intervention and not by a new intellectual synthesis between those demanding mathematics teaching close to the intuitions of engineers and those demanding mathematics teaching that would open doors to a globalized culture of science. In other words, the Brazilian case represents neither the (short term) victory of tradition, nor the (long-term) victory of modernity, but rather a missed opportunity to negotiate local and global knowledge.

As we were able to show in this paper, the modernist approach represented by mathematical axiomatic rigor did not simply prevail (even if only temporarily) because it represented the most progressive direction in mathematics, but rather because of very specific local political circumstances. Mathematical axiomatic rigor was adopted by Fantappiè, who was appointed by Theodoro Ramos, a member of the university's organizing committee, appointed by the president of this committee, de Mesquita, who in turn, was appointed by the govenor of the state of São Paulo, de Salles, who was elected by the people of São Paulo. This, finally, leads back to the final negotiations after the Constitutionalist Revolution.

The history of the universities in Brazil is neither connected, as it was in other countries, with overcoming ecclesiatic traditions in favor of laical education, nor with the establishment of a nation state encompassing this education. In fact, Brazil after the Proclamation of Republic had laical education as a principle. Compared with the other Latin American countries, Brazil was an economically and culturally successful nation, even though it did not yet have a university. Certainly, the idea of a university was closely associated with certain liberal ideas. The beginning of the twentieth century saw political changes in several countries throughout the American continent, which were characterized by the strengthening of the liberal movement and promotion of universities. Nevertheless, the "liberal context" was in itself not enough to actually create a university, as the several failed attempts in Brazil illustrate. Only specific favorable circumstances such as those associated with the Constitutionalist Revolution enabled the Brazilian liberal movement to finally create a university.

Was the creation of the USP thus a historical accident, happening so late that it actually no longer made a difference to the development of Brazil as a nation? To respond affirmatively to this question would mean to ignore another important context of the university's creation that we have hardly touched upon here, that of the Industrial Revolution which took place in Brazil in the 1920s. It would have been hardly possible to sustain this Industrial Revolution and attain the present state of development without the flourishing Brazilian university system which began with the creation of the University of São Paulo. But even this affirmative answer leaves other questions open for further study: what university model would best serve the specific demands of Brazil today, and was the model whose establishment under rather contingent political circumstances in the 1930s that we have reviewed in this paper really without alternatives?

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Chapter 19
Celestial Navigation and Technological Change on Moce Island

Jarita C. Holbrook

19.1 Introduction

The islands of Fiji are located one thousand miles north of New Zealand, in the "Melanesian" part of the South Pacific. The people who settled Fiji are thought to have migrated from Indonesia across the Pacific, island hopping from landform to landform and reaching Fiji around 4000 years ago. The oldest archeological sites in Fiji are dated at around 1300 BCE (Kirch 1997).

In 1998, I had the opportunity to travel to Fiji to assess Fijian astronomy and celestial navigation. The term celestial navigation is often connected to the mathematically intense altitude intercept method that uses a sextant and nautical charts. Here celestial navigation is used in its broadest sense of navigation using celestial bodies. In locating a research site, my initial inquiries into contemporary Fijian navigation revealed that the Moce islanders are considered the best sailors of all of Lau, and the Lauans are considered the best sailors in all of Fiji. "Moce" pronounced "mo-they" means goodbye or goodnight in Fijian. One Moce islander, Simione Paki, had acquired some national fame for having sailed from Moce to Suva, the capital of Fiji, using 'traditional' methods in a double-hulled canoe. I use "traditional methods" to refer to the methods used by the oldest generation of navigators on Moce who are over seventy years old. Used in this way, traditional methods do not necessarily indicate ancient methods, or even methods used prior to this oldest generation. In 1998, I was able to travel to Moce Island and collect interviews with many men who navigated. In 2003, I returned to conduct additional interviews and follow-up on information collected in 1998.

Moce Island, which is some 325 kilometers (172 nautical miles) from the capital of Fiji, Suva (Figure 19.1), is about ten square kilometers in size and roughly circular in shape. The Lau group extends about 250 nautical miles north to south. Moce is in Southern Lau and is one of the easternmost islands in the group. There are two villages on Moce: Korotolu and Nasau. Today, with a population approaching six hundred people, the two villages have merged. However, the architectural style of the two villages has remained distinct: the houses in Korotolu are primarily oval in shape with a single room, while in Nasau, the *bure* houses are

Figure 19.1: Map of the Fiji Islands.

rectangular with several rooms, thus reflecting historical differences in the original settlers.

According to the people of Moce, there was a group of smaller darker-skinned Fijians living on Moce when a group of people from Tonga arrived. The Tongans asked permission to stay and set up a village some distance from the original village, Nasau. About one hundred years ago a whale was beached on the reef near the Tongan village, and for months the smell of the decomposing carcass made living there unbearable. The new settlers asked permission to relocate to a site closer to Nasau and named their new village Korotolu which means third village in Fijian. The Moce Islanders estimated that the move occurred about one hundred years ago, however, Laura Thompson (1972, 136) gives the date of Leva village moving to Korotolu as 1921. Today, only the descendents of the original inhabitants are allowed to bury the dead on Moce. This was the only instance I observed where origins were relevant. There has been and continues to be considerable intermarriage between the two groups.[1]

Figure 19.2: Remains of the canoes used for the famous trip to Suva.

Near Suva, there is a group of Moce Islanders in diaspora living in a village named Korova (fourth village). In addition to being the capitol, Suva is the largest city in Fiji with a population of over 73,000 people. I conducted my preliminary inquiries into the navigation practices of the Moce Islanders in Korova. Simione Paki's son, Semiti Cama Paki, lives in Korova and provided me with information about his father, the famous trip to Suva, and allowed me to photograph the remains of the canoes used for the voyage (Figure 19.2). The people living in Korova were very excited about the possibility of me studying Moce navigation. They were eager to have their traditions recorded.

From the information provided in Korova, I determined that the Moce islanders used celestial bodies as part of their navigation. I made the decision to travel to Moce and talk to Simione Paki in order to find out more about the navigation methods. My plan was to interview Paki and the other navigators on Moce. I hoped to discover the Fijian names and English equivalents of as many celestial bodies as possible, including those used for navigation, and to gain an understanding of the mechanics of their system of navigation. In this chapter, I report my findings on the navigation techniques but discuss only those celestial bodies used in navigation.

[1]Fijians have maintained their chiefly system of local governance. The choice of the chief of Moce is dependent upon bloodlines, but it was not obvious to me that they were chosen exclusively from the descendents of one village over the other.

My data collection methods included interviews, informal discussions, and paying attention while I was traveling in boats. I used snowball sampling to identify individuals who potentially had knowledge about navigating. The interviews were semi-structured with a list of questions focusing on gathering demographic information, navigation skills, and experiences navigating. The interviews were conducted in English or in the Moce Island dialect. Though I have some competency in Fijian, I could not follow the Moce dialect, thus I worked with local translators. The translators often sat in on my interviews even when they were conducted in English and would occasionally interject in the local language when it was clear the person being interviewed did not understand my question. I documented my research through field notes, digital recordings in 2003, and photographs. My primary goal was to learn their navigation methods that used celestial bodies, what I learned about technology was secondary.

19.2 Navigation Techniques of the Moce Islanders

In 1998, my research on Moce began with interviewing Simione Paki. I went on to interview a series of men: sailors and farmers ranging in age between 54 and 84. During these interviews, I focused on the mechanics of their system of navigation, the use of celestial bodies for navigation, their knowledge of celestial bodies, the places to which they had traveled, and their sailing stories. The sailing stories often involved surviving a storm, hurricane, or being capsized. Some involved getting lost and improvising to get back to Moce. The improvisations included cutting the size of the sail using a knife or cane knife (machete) to reduce wind resistance, tying objects to the hull to increase the drag, and maintaining their course by marking the wind and/or current directions under low visibility conditions.

One example of a survival story was told by Johnny Rapui (~40 years old), who was sailing back to Moce when he encountered a hurricane. He cut down the size of his sail so that it would catch less wind and maintained his course to Moce. He arrived safely.

I have chosen to present the narrative of Simione Paki reconstructed from my field notes in this section. It serves as a typical example of the navigation style of the Moce Islanders including wind directions, visual markers, and knowing when to reset the sail and change directions. However, Paki's story is unique because in the early 1990s he sailed an exceptionally long distance, from Moce to Suva, using traditional methods. Most of the men have sailed only the extent of the Lau group of islands. The difference is not only the distance, but that when sailing in the Lau group one is rarely out of sight of land, whereas the route to Suva involves stretches of many hours on open ocean.[2] Paki is also unique in that he sailed

[2]At this point scholars of long-distance voyaging may scoff at the relatively short distances traveled by the Moce Islanders. However, very little has been published on any aspect of Fijian navigation and even documenting the techniques for short voyages is a significant contribution to Pacific navigation literature.

weekly to other islands in the Lau group and occasionally to Tonga using Fijian canoes and using traditional methods,[3] whereas the other interviewees made a few long trips a month. Paki is 72 years old.[4] Today, he sails to his garden about a mile away from his home most mornings to collect vegetables for his family's consumption. What follows is a summary of Paki's narrative.

The trip to Suva was initiated by one of Paki's sons, Metui. Metui thought that it would be a good financial enterprise to have traditional canoes in Suva to give tourists rides for a fee. There are no hardwood trees on Moce, thus they traveled to Oneata[5] and acquired a double-hulled canoe and a single canoe for the trip. In the last week of February in 1992, by my calculation,[6] on a Friday, Simione Paki, his son—Metui, and a third man set out for Suva.

They sailed to Olorua Island (west of Moce) and had originally planned to spend the night there, but since the weather was so nice, they continued. When they reached halfway between Vanuavatu Island and the reef near Tavu-na-sici, the wind was blowing from the east. They set their sail and went southeast to Totoya Island. Once Totoya was sighted, they reset their sail for Moala Island. When they reached Moala, the wind changed to east-southeast, so they changed the sail to go west towards Suva. On Sunday night, they sighted the lights of Suva, however, at that point the wind was not good. They reached a small island very close to Suva and spent a few hours there resting. The next day, they sailed on to Suva, reaching there at four in the afternoon on Monday. There the narrative ends.

After listening, I asked him questions about the details of his voyage: The entire trip took four days and three nights. Paki marked the time using a radio, which he carried in his canoe. There is no indication that keeping track of time was part of his navigation technique. His technique was to change directions when certain islands or reefs were sighted. The trio carried their own supply of food, water, and a Primus (kerosene) stove for cooking. Paki learned the route from riding on commercial boats between Moce and Suva. Again, the reason for the voyage was to take canoes to Suva as a commercial venture to offer tourists rides in Fijian canoes.

There is a second part to the story: In December 1993, Metui and a friend set sail for Suva in another double canoe. They were last sighted off Moala, but never reached their destination. A month later, their canoe washed up on Kadavu, an island south of Suva. Both Metui and his companion were presumed dead; their bodies were never recovered.

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[3]"Traditional" as mentioned in the text. I mention this here again because this sailing method only reflects the techniques used by the oldest generation of navigators on Moce, not necessarily an ancient Fijian navigation method.

[4]Ages are given for 1998, the time of this study.

[5]Oneata is one of the few islands in the Lau group that has trees large enough to make canoes.

[6]Paki said that they left on a Friday in February in 1992 and the moon was past full. Using astronomy software I determined that this was Friday, 21 February 1992.

Historically, the people of Moce would make long trips to Tonga, which requires sailing for several days without sighting land, rarely to Suva.[7] The wind patterns generally travel from west to east for part of the year,[8] and since Tonga is east of Moce they would travel with the wind. The people of Moce estimate that they took their last big trip to Tonga in the 1950s. When asked why such trips stopped, they said that the big traditional canoes called *drua* were no longer being made and that the trip is not easy in a smaller boat. Sometime in the 1980s, a boat containing a Tongan man washed up on the reef. He had run out of petrol while fishing in Tongan waters and been adrift for one month. When greeted he did not respond because he thought it was another of the many hallucinations he had experienced while adrift. Eventually he was returned home to Tonga. This drift story shows that the current travels from east to west during some part of the year, too.[9] Paki also made trips to Tonga in his canoe as a lay preacher. Tantalizingly, in 1998 Paki mentioned (via the translator) that he used "the star to Tonga" when he traveled to Tonga. Paki was the only Moce navigator to mention this star and during my 2003 field visit I was able to determine that he was referring to Venus. He used Venus setting in the West in the evening, which he placed at his back to go to Tonga.[10]

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[7] An interesting article on the history of voyaging between Fiji, Tonga, Samoa, and other Pacific Islands is (Lemaitre 1970). Using a variety of historical techniques he tabulates the number of inter-island groups travel.

[8] This wind pattern, referred to as the Winter Trade Wind, travels from the southeast (Finney 1996).

[9] Finney (1996, 99) states that during the summer months, the winds blow from the southeast but take on a south to north circular pattern. Maps given in (Lewis 1994, 142–43) show the ocean current travelling from east to west during August–September and February–March.

[10] What follows is part of the transcript for that interview with Paki. This shows how difficult it was to grasp some of the nuances of their navigational technique. Also, these are actually the translations of what Paki said in the Moce dialect.

> JH: When you left Moce and went out to sea and headed towards Tonga did you use the stars?
>
> SP: We left Moce during the day. We only used the stars during nightfall in the evening: the Naivolabongi.
>
> JH: Navolabogi?
>
> SP: Naivolabogi.
>
> JH: That star, is it directly over Tonga or?
>
> SP: Yes, directly over Tonga. The Naivolabogi rises directly over Tonga. The Naivolasiga, you can see it during the evening.
>
> JH: When it is night time the Naivolabogi is right after sunset. It is near the sun, so it is actually in the west, right? Where Tonga is in the east.
>
> SP: I think it is directly over Tonga because it is in the path of the sun. The Naivolasiga comes in the early in the morning. The Naivolabogi in the evening.
>
> JH: Is that the only star you use in the evening?
>
> SP: Yes, the star that is directly behind you …in the west.

In most cases, including with Paki, the men provided information on the celestial objects used as part of their system of navigation only after I asked, not during their descriptions of how they navigated. Then they would mention the Volasiga, the Volabogi, the Sun, and the Moon. *Siga* means sun and day, while *bogi* is night; *vola* is to mark. Thus loosely translated *Volasiga* is mark the day and *Volabogi* is mark the night. For completeness, *vula* is Moon. The men described using the sunrise, sunset, moonrise, and moonset to mark the general directions of east and west. The Volasiga and Volabogi are bright stars that appear near sunrise or sunset, i.e., the planet Venus[11] when it appears near sunrise and sunset, respectively. The Volasiga and Volabogi were used in the same way as the Sun and the Moon to get a rough estimate of east and west. The men said that they were especially happy when they would sight the Volasiga for it meant that the Sun was coming up soon. Thus, the Moce Islander's celestial navigation

1. only included the Sun, Moon, Venus, and possibly other visible planets, thus they only used planetary bodies and
2. these celestial bodies were only used near the horizon when they were rising or setting in order to find east or west.

19.3 First Phase: Blown by the Wind

The use of celestial bodies was only one part of their navigation system and given that the navigators had to be prompted to speak about it, a not so important part of their navigation system. The Moce Islanders in my first set of interviews had a tremendous knowledge of the passages through the local reefs, the currents, and the wind patterns in the Lau group. As with Paki's narrative, the stories that they told me during their interviews[12] contained detailed information such as a change in the direction of the wind or the direction from which the waves were coming (current direction) as noted by how the wavefronts broke against the hull. When they were required to change the sail, how many times they had to change the sail, and the sighting of islands and reefs, all punctuated the stories. The Moce Islanders gave the impression of having set routes for travel between the various islands of the Lau group. Included in their system are natural markers that had to be sighted before changing their sails.

The system of navigation depended first and foremost on an intimate knowledge of the wind and current patterns along with knowledge of the locations of reefs and islands, both uninhabited and inhabited. The only celestial bodies that were part of their navigation were the Sun, the Moon, and Venus. These planetary

[11] The navigators, especially the second set of interviewees, were not all in agreement that both the Volasiga and Volabogi are the planet Venus. From their comments, namely that the Volabogi is after sunset and is brighter than all the other stars, and some went so far as to say that every night there was both a Volabogi and a Volasiga. I deduced that the Volabogi in some cases might be whichever other planet is visible at night be it Mars, Jupiter, or Saturn.

[12] For more about the stories, see (Holbrook 2007).

bodies were used to mark east and west upon rising and setting, and served as a rough compass used as a secondary method to check their bearings.

The interviewees learned to navigate as children by traveling in boats and watching the navigators. Children are included on fishing trips and inter-island trips, the adults often allow the children to help with the sailing and navigating. None of the interviewees indicated that the adults gave formal lessons in sailing, instead the children had to pick it up as they went.

The boat on which I traveled to Moce from Suva also transported about ten people returning home to Moce. While on the boat, I questioned these individuals about their knowledge of navigation and came to the conclusion that certain stars, the Moon, and the Sun were all used as part of their system of navigation. Thus, after conducting the first set of interviews I was confused by finding that only the Sun, Moon, and the planet Venus played a role in their system—the stars were missing. I returned to the people I spoke with on the boat and interviewed them; they provided details that led me to conduct a second set of interviews.

19.4 Navigation Techniques of Moce Islanders Phase II: First-Generation Stellar Navigators

The second set of interviewees averaged 42 years in age, were male, and had lived primarily on Moce. They tended to have traveled many times to Suva (via government boats) to work or visit relatives. They had completed primary school and had often attended secondary school away from Moce at the school on Lakeba or one of the schools in Suva. Their voyaging was limited to islands within the Lau group.

The second set of interviews began with Alifereti Amani, 42, which I present as a narrative typical of the younger navigators (Figure 19.3). His narrative is derived from my fieldnotes. Amani was one of the people I met on the boat to Moce and, as with most of the interviews in this group, the interview was conducted in English.

Amani described how when traveling to another island, after exiting the reef, he would place Moce at his back at the correct angle to reach his destination until Moce disappeared from view or the next island marker appeared on the horizon. Although the next island is not visible, the Moce men know its direction relative to Moce. When twilight falls, if he has not reached his destination, he picks a star that marks the direction in which he is traveling. He follows that star until he reaches his destination.

Again, after listening to his description, I asked questions to learn more about using the stars and other navigation equipment: If the star that he is following rises or sets, he picks another star in the right direction. He said that there are plenty of stars in the sky, that is, there is no shortage of stars in the direction they wish to go. The stars he uses do not have names in Fijian. When asked, he was very firm about there being no magnetic compasses on Moce.

Figure 19.3: Alifereti Amani (on top) helping to repair a boat.

The interviewees in the second set all said similar things. They spoke of their knowledge of exiting the reef, using Moce or other islands as navigation markers, and at night using stars in the correct direction as beacons. There was no mention of current and wind patterns. However, they did name the Volabogi, Volasiga, and the Sun and Moon and how they are used in navigation as rough east/west markers. They all said that they did not use a magnetic compass.

19.5 Technological Change: Motoring Along

The second set of interviews provided information on how stars are used in Moce navigation. The original narratives did not mention stars, but used the Sun, Moon, and Venus as part of their method of navigation. Noting the change in technique, I began to search for reasons behind the different methods. I began to explore the possibility that a change in boating technology caused the change in navigation.

The older men used traditional canoes with sails. The younger men originally learned to sail, but over the last two decades, the outboard motor has become common and the islanders have switched to wooden and fiberglass boats and punts. Today, there are very few traditional canoes on Moce—even Paki uses a punt with a sail.

The fact that boats are driven by outboard motors appears to have had more effect on navigation than the shape of the boats or the materials used to construct them. The outboard motor allows the boats to travel in straight lines, independent of the wind and current. The outboard motor significantly reduces the travel times because tacking is no longer necessary; in addition, with the canoes they actually shunted, which means that in order to change directions they would remove the mast from one end of the canoe and place it on the other end of the canoe. Shunting is a much slower process than tacking. In regard to navigation, this means that visual markers have come to dominate the method of the Moce Islanders. Bearings in relation to islands, reefs, and stars rather than settings of the sail and wind directions punctuated the narrative of Alifereti Amani and his contemporaries. It is the inclusion of stars in the new method which makes the Moce case unique in the Pacific where, in general, navigation methods that use celestial bodies are in decline.

I went on to learn more about the impact of the outboard motor on the use of stars for navigation in the remaining interviews. The men who use the new method consistently said that they taught themselves or "figured it out" themselves. I was startled by the narrative of an older man in his seventies who spoke of using the stars to mark his way home from Lakeba to Moce, because I had thus far concluded that only those in their forties or younger would use the new method. However, he told me that he was using a motorboat at the time, which was consistent with the connection between the use of the outboard motor and using the stars. As with the other men, he said he learned the technique of using the stars in this manner himself. In general, the outboard motor users felt that using the stars was the most obvious thing to do at night while traveling. The younger generation of navigators also told tales of capsizing and having to cut the sail in bad weather, but these were stories from their youth back when they used canoes. None of the informants claimed to have had formal naval or navigation training and did not describe their techniques nor distances in nautical terms.

The new system and the old system of navigation are admittedly inexact, but sufficient for the type of navigation performed by the Moce Islanders. Travel undertaken by the Moce Islanders in smaller crafts is limited to destinations within the Lau group—rarely is an island or the water breaking on a reef not visible during travel. Thus, the homing skills necessary for long-distance ocean voyaging are not found in the interviews.

The new method of navigation including the stars is being transmitted to the next generation through watching and doing. The children of Moce are often given command of the boats while traveling with adults and are told to keep the motor pointed towards a particular star when traveling at night. Their training is thus more of an apprenticeship of convenience rather than formal.

Once I was better able to articulate the two navigation techniques, I returned to the first set of informants and asked them how they felt about the new technique. All the men praised the fact that traveling by motorboat was much faster than sailing. A few thought the new method was bad because the motorboat users no longer paid attention to the wind and current. They explained that the drawback to relying so heavily on visual cues is that when visibility declines, such as during a storm or in fog, they get lost unless they were paying attention to the wind and current.[13] It was clear that the knowledge of wind and current patterns was considered to be the most important part of navigating for the old Moce sailors. They felt that this particular knowledge should not be forgotten.

19.6 Discussion

The situation on Moce is the first case I have found of a celestial navigation system being developed because of an introduced technology: the outboard motor. In this discussion, I examine other cases in the Pacific where a new system of navigation includes more celestial markers. I explore possibilities for why a stellar system of navigation was not present on Moce before the introduction of the outboard motor. I touch on earlier studies of Fijian and Lauan navigation techniques, technology transfer, and economic changes related to boat building. I end by presenting examples of similar responses to a change in navigation techniques from other communities of navigators.

Of the contemporary studies of Pacific navigators,[14] the majority of cases showed a loss of the celestial aspect of navigation as the navigators became more dependent upon modern navigation equipment. The authors often had to search their fieldsites for the few remaining celestial navigators. This was definitely not the case in Moce. One of the studies did mention a change in navigation technique towards a celestial one, but the circumstances did not involve a response to a change in technology: In Lewis' *The Voyaging Stars*, Siona Mafi of Nomuka Island in Tonga is presented as someone who was formally trained in the use of charts and compass, but got tired of using them. He developed a celestial system by first using the compass to note the rising and setting positions of certain stars, and finally using the stars alone (Lewis 1978, 85; Lewis 1994, 32, 121). Unlike the Moce case, he was not motivated by a change in boating technology.

Another possible example of an ad hoc celestial navigation system can be found in Feinberg's *Seafaring in the Contemporary Pacific Islands*. In his article on the Nukumanu Islanders, when the author asked which stars were used for navigation, he was told that each navigator chose his own set of stars (Feinberg 1995, 189). The author did not believe that this was true, but instead thought that they were being secretive. He managed to get only one informant to name the set of stars that he used. The Moce case may cause him to re-evaluate his initial conclusion since they also use stars that do not have formal names, and use stars that are convenient for each particular trip.

[13]This idea of being able to navigate under storm conditions I explore in more detail in (Holbrook 2007). It is combined with data from two other fieldsites in my unpublished manuscript *Following the Stars* as part of a theory on the connection between storytelling and technology transfer.
[14]See (Lewis 1978; Finney 1976, 1994; Feinberg 1995; Goodenough 1996).

There is a similarity between the new method of Moce navigation and navigation techniques found in other parts of the Pacific. In the late 1960s, David Lewis recorded the words of a Tongan navigator, Kaloni Kienga:

> You head towards that star [...] and when it has moved too high and too far to the left, you follow the next to arise from the same point on the horizon. Then the next, and the next, and so on until dawn. This we call *kaveinga*, the star path. (Lewis 1978, 18)

Kaloni Kienga only named the first star, which he pointed out to Lewis; the other following stars he did not name. Lewis found this method in use in many other parts of the South Pacific, where the location of island groups is marked by the rising and setting of a "bright" star and the course is maintained by following a chain of less prominent stars. The Fijians currently use a convenient star (not necessarily a bright one) that is not named but also use successive rising or setting stars. This technique clearly marks the beginning of a new *kaveinga*-like system.

The ethnography done by Laura Thompson mentions the methodology of celestial navigation she found on Kabara, an island about twenty nautical miles to the southeast of Moce (Thompson 1940, 177). Her informant, Risolo, said that each island had several stars and when one star rises or sets another star is chosen. She clearly states that only the most experienced navigators used the stars. Her informant explained that it was secret knowledge. Seventy years later, I interviewed Thompson's informant's nephew, who had trained under his uncle. He referred to his use of the stars for navigation as "my secret weapon," similar to what Risolo had said. The method sounds identical to the one now used by the Moce navigators, however, the Moce Islanders insist that they taught themselves this method and the method is not a secret on Moce Island.

Why given similar traditional boating equipment across the Pacific did the Moce Islanders not have a *kaveinga* system before now, especially since at least one person on Kabara had such a system? Is a *kaveinga* system typical of long distance ocean voyaging, which the Fijians rarely pursued during the last century?

> The old people before, they use to say that they use the stars as a mark when they travel at night. If there are one, two, three stars and they are bright, and are directly over an island, they are going to keep it, and they will work out just to use the stars as their compass. (Moce Interview 01/03)

Even if they taught themselves how to navigate by the stars this does not mean that their ancestors did not navigate by the stars. In fact, most Moce navigators believed that in their grandfathers' time, more people knew names of the stars and how to use them to navigate. The young navigators of Moce may be recreating an older Moce *kaveinga*-like system on a much smaller distance scale. If the new method is indeed a revival of an earlier tradition, the Moce Islanders are firmly unaware of it for all claimed to have made up the new method themselves. The Moce navigators in both sets of interviews did think that perhaps their forefathers knew more stellar names, but none connected this to a lost system of navigation that relied more heavily on celestial markers. Anthropological studies in the 1920s and 1930s do not support this view that previous generations knew more stellar names (Hocart 1929; Thompson 1940). Although, neither study includes information on Moce navigation, Hocart recorded the traditions of many of the Lau Islanders, and as today, those that used the stars to navigate did not know the names of the stars. In addition, there is the question of the Tongan influence on Moce navigation. The Moce Islanders presented their system of navigation as their own; there was no distinction between the systems described by the inhabitants of Nasau or Korotolu (the two villages on Moce). If there had at one time been such a distinction on Moce, since one village is of Tongan origin, it has been forgotten.[15]

At latitudes of the United States—greater than thirty degrees north—people are familiar with Polaris which marks the north celestial pole. Over the course of the night, certain constellations close to Polaris are seen to circle the pole, further emphasizing the location of the north celestial pole and therefore north. Thus, most of the navigation systems we find at these latitudes utilize Polaris and constellations that allow one to find Polaris. At the latitude of Fiji—eighteen degrees south—Polaris is not visible, nor is there an obvious marker for the south celestial pole. All stars rise in the east and set in the west following the path of an arc. Given that the stars move in this manner, the obvious way to use the stars for navigation in this part of the world is to follow chains of rising and setting stars. Once the motion of the stars is understood, it is possible the theories of technique transfer or technique revival are no longer needed to explain the celestial navigation method.

Going back to the question, especially now given the understanding of how the stars move at these latitudes, why didn't Fijians have a *kaveinga*-like system? It is my opinion that given the short distances Fijians traveled while sailing, a *kaveinga*-like system may have proved too inexact. I hypothesize that when sailing over long distances, the zigzag pattern necessary to maintain a heading under sail would average out to a line. However, for traveling short distances, traveling too far without resetting the sail may cause you to overshoot your destination. Thus,

[15] Goodenough and Feinberg (1995) mention that historically Fiji has relied on the skilled Lauan sailors to make up the ranks of their navy. This reflects the contemporary belief that Lauans are the best sailors in Fiji. Historically, in his study of various islands in the Lau group (he did not include Moce) Hocart (1929) mentions that the Lauans had a unique indigenous directional system with three major directions. Neyret (1950) also talks of this direction system and uses the same Fijian names as Hocart. I found no such designations on Moce. Though, similar to my findings, Neyret concluded that the navigation methods of the Fijians are vague. Neither researcher mentioned chains of stars being used for navigation which is consistent with what I found with the older navigators.

the set routes which included when to tack may have proved more accurate than following the stars. I have had no feedback on this theory with the Moce Islanders.

19.7 Technological Change in Lau

The implications of technological change add another complexity to studying contemporary celestial navigation. Why has the outboard motor been adopted into Moce culture,[16] yet the islanders are very proud that there are no magnetic compasses on their island? In the broadest sense, how do people decide which technology to adopt and which to reject? I examined other cases of changes in boating technology in Lau in an attempt to answer these questions:

> Lauan sailors say that a mat sail is better than a canvas one for the mat allows the wind to pass through and therefore the mast is not easily strained or broken. (Thompson 1940, 176)

This passage is significant because it shows that introduced technologies were in Lau over sixty years ago. At that time, the Lauans were not eagerly adopting the new canvas sails, but instead tested them and found that their own mat sails better met their needs. Further:

> Salvaged hardware from shipwrecked yachts is commonly adapted for use on Lauan sailing canoes. Friction hitches and simple mechanical advantages, in conjunction with simple wooden hardware, are used in the rigging of a sailing canoe. (Gillett 1993, 41)

This shows that the people of Lau are amenable to adapting new technology if there is a clear advantage.

On Moce, the outboard motor has a clear advantage over sailing because it has led to faster inter-island travel. The compass they have rejected and therefore, following the logical flow, their navigation system must be superior to the compass. The compass may be at a disadvantage because in a small boat the shaky needle of a compass is difficult to read.[17] Or it could be that the Moce Islanders take pride in knowing their surroundings in great detail and that somehow their reputation as being the best sailors in Fiji is entwined with not needing compasses.[18]

The Moce Islanders have switched from using canoes to using punts and boats. Though I did not question the navigators about the pros and cons of the change in boats, I imagine that the roominess of the new boats is an advantage. An

[16] For an example of a culture that has not successfully adapted the outboard motor due to economic difficulties, see (Montague 1995, 59).

[17] For an example of a culture that has adapted the compass as well as modified the boat design of larger boats to accommodate motors, see (Ammarell 1995). The Bugis of Indonesia use both the compass and celestial navigation in their voyaging. Ammarell includes extensive information about the astronomy of the Bugis and their wind compass.

[18] I did not question people as to why they did not use compasses, thus I can only speculate.

outboard motor easily fits to the back of the punts as opposed to the tapered end of the canoes. Interestingly, Lewis states that the Fijians around the Koro Sea (west of Lau closer to Viti Levu) called their canoes *waqa ni tagane*—boats of men (boys), whereas the punts were called *waqa ni yalewa*, predictably, boats of women (girls) (Lewis 1978, 110). This division may imply that the Fijian canoe is regarded as more manly than the punts, or that women preferred to travel in punts. I found no such distinctions on Moce or other references that would shed light on this designation.

Another author to comment on the adoption of technology and the change in boats in Fiji is G. K. Roth:

> There has been a marked effect on the regular use of traditional, Fijian-made articles through the introduction from overseas of tools and utensils and other manufactures, all of which have tended to displace the former but have not always displaced them entirely. The result is that many introduced articles exist in modern times side by side with those which they are gradually replacing. Instances are to be seen any day and in every island: […] English fish-netting in place of nets made from local vegetable fibres; boats and punts in place of dugout canoes, some with outrigger attachment and sail […]. (Roth 1953, 43)

Historically, one economic factor which led to a revival in canoe building and sailing occurred in the 1930s when copra prices fell. Copra is the dried fruit of the coconut. When copra prices were high, the Lauans sent their harvests to the refineries via the larger government and commercial boats. Thompson notes that while copra prices were high, copra was harvested and exchanged for goods and "[…] they began to neglect their other economic pursuits such as fishing, gardening, canoe building, and interisland trade" (Thompson 1938, 196). Once the prices fell the number of boats servicing Lau dropped from six boats to one (Knapman 1976). The Lauans could no longer afford to pay the shipping fees and began using their sailing canoes to transport the copra (Ladd 1935). This circumstance allows for a possible historical comparison with the current technological changes. During the time of reduced canoe travel, did the Lauans lose or modify their traditional navigation methods? Only a few of the Moce Islanders were of an age to navigate during the 1930s. The oldest navigator that I interviewed, Biu (84), was part of the crew on one of the larger boats during that time. However, his career on the ocean was brief because he stated that he has been a farmer for most of his life. He did not know most of the navigation techniques practiced by his neighbors. Thus, the interviews from Moce did not include any new information which could shed light on this issue. Regardless of their past history of adopting new technology, the Moce Islanders today have accepted both the outboard motor and a change in boating design to accommodate the motors.

Moce is not the only location where I have studied contemporary celestial navigation (Holbrook 1998, unpublished). My research at the United States Naval

Academy has shown that contrary to the belief that celestial navigation is a continuous tradition leading back into antiquity, celestial navigation as practiced by the military was not perfected until the invention of the chronometer at the end of the eighteenth century. Moreover, it has continued to be modified by innovations in technology such as the calculator and publications such as the Nautical Almanac as well as electronic navigation instruments such as radar, Loran-C, and the NAVSTAR GPS. My research on the navigation of the Kerkennah Island fishermen found that the celestial navigation aspect of their navigation system is in decline. However, the decline in the teaching of celestial navigation is not due to new technologies, but because of education. Young fishermen are now attending school instead of spending time fishing. These findings as well as the Moce case may cause scholars of Pacific navigation to consider how ancient the navigation methods are. It may be more appropriate to call navigation methods observed today the latest techniques or "surviving techniques" rather than traditional. It is reasonable to suppose that navigation techniques that rely on no external instruments could have been practiced thousands of years ago, but I do not think it is wise to insist that these techniques have been handed down without change to the present.

19.8 Conclusions

The navigators of Moce use a complex method of navigation that can be distilled down to two navigation techniques: the old navigation system emphasizes the skills necessary for sailing, whereas the new method is ideal for the linear travel that is possible using motors. The new system of navigation incorporates more celestial markers than the old. In particular, the old method used the Sun, Moon, and the planet Venus as celestial east-west markers; the new method adds the use of rising and setting stars. There is a possibility that the new method of using stars is a revival of an older navigation system, however, the evidence from interviews is overwhelmingly against such a conclusion. Instead, the navigators uniformly say that they invented the method of using the stars themselves and that the new system is the simplest method given motorized boats. I add that, given the motion of the stars at these latitudes, using chains of stars is the obvious choice for navigation and suggest that for short-distance sailing set routes were more practical than following the stars. The new navigation technique is a direct result of the introduction of the outboard motor.

I wrote a statement in my field notes dated 5 August 1998. I shared what I wrote with three Fijian men who agreed with what I had written and signed their names: Alefereti Amani, Metuiselo Mua, and Savenaca Waqabaca. I include the first three paragraphs here:

> After several interviews with the old men and a few of the men in their thirties and forties, it is clear that the outboard motor has radically changed the way that navigation is done on Moce. Moce were known

> for their skills or expertise in sailing. They used the traditional Fijian canoes with sails made of voivoi, the same material they use for their mats. The old men went on and on about how they know the currents and the winds, they know the way into, out of, and around the reefs. When asked about the stars, [they said] they used where the sun sets and the moon rises to find the cardinal directions. Then the volibogi and volisiga to check them. When I spoke to the younger men who now use outboard motors, they speak of using stars which rise over the islands or in the direction of the island they are going to. When that star rises too high, they pick another one below it. The method of transmission for the sailing was by way of traveling with the old men and just paying attention to what they were doing. The old men said that the only thing that their fathers told them was how to get out of the reef, same for the younger men.
>
> The outboard motor allows the boats to travel in straight lines instead of tacking back and forth. One of the old men said the outboard motor is bad because in low visibility situations with a sail you still know your course and if you know the current you can maintain your course. With the outboard, unless you have been paying attention to the wavefronts, you have to wait until you have visibility again.
>
> Other old men say the outboard is good because you don't have to tack. The younger men have accepted the outboards as their boats for everyday use [sic]. They acknowledge that the punts and especially the fiberglass ones are much faster than the traditional canoes.

This entry was meant to summarize my findings for the 1998 research and to share with the Moce navigators. It captures the role of the outboard motor and the connection to now including stars in their navigation methods. That said, both the old and new systems of celestial navigation are inexact but sufficient for the navigational needs of contemporary Moce islanders.

Moce serves as another case of the complex interaction between globalized technologies and navigation. In 1962, the Bugis of Indonesia were mandated to include a compass on board boats larger than fifty-two cubic meters. Similar to the debate on Moce, the traditional Bugis celestial navigators feel that the younger navigators rely too much on the compass. The older generation uses the compass as a secondary check to their celestial methods (Ammarell 1995, 1999). My own research at the United States Naval Academy revealed a similar debate about the Global Positioning System. In general, the older officers feel that there is too much dependence on the GPS and the art of celestial navigation is being lost. However, officially, celestial navigation is used to check the accuracy of the positions returned by the Global Positioning System, and therefore celestial navigation continues to be taught at the Naval Academy. Thus, the Moce islanders are not unique in changing their navigational technique in response to globalized technologies. However, they remain unique in that the change was stimulated by the outboard motor rather than a new type of navigation device.

At the end of his article on Amplett islanders' navigation, Peter Lauer states:

> As the Amplett men are considering buying a motor launch [...] it seems likely that the spread of modern means of transport may soon begin to alter the inter-island voyaging techniques described [...]. (Lauer 1976, 89)

Moce is a case study in this type of change. However, I doubt that Lauer envisioned that such a change could include the utilization of stars in a system of navigation previously devoid of them.

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Chapter 20
Translation of Central Banking to Developing Countries in the Post-World War II Period: The Case of the Bank of Israel

Arie Krampf

20.1 Introduction

During the post-World War II period (1946–1975), more central banks were established than in any other three consecutive decades before or after. Most of these were established in developing countries after they had become sovereign states.[1] On the nominal level, it was a case of global convergence. However, examining the policy instruments that central banks employed in different countries, one finds a pattern of divergence or regional convergence: central banks in industrial countries converged around the Keynesian model of central banking while central banks in the periphery converged around a different model.

The analysis of this phenomenon hinges upon several broader and fundamental questions. It raises questions concerning the encounter between economic knowledge produced in industrial countries on the one hand, and the unique institutional structures that prevailed in developing countries on the other. Secondly, it also raises questions concerning the respective roles of national interests and pressures in the international system, as well as processes of learning and experimentation in cases of policy transfer between countries. Finally, it raises questions concerning the relationship between processes of state formation and globalization. State formation is understood here as the transformation of local institutions and authorities as well as the construction of bureaucratic structures that enhance the capacity to govern the economy. Globalization is understood as the diffusion of global standards, rules and policy instruments.

In this chapter, I attempt to explain the fact that a large number of developing countries adopted similar policy instruments within a relatively short period of time. I argue that it can best be explained as a process of policy translation. Moreover, I argue that the capacity of states to translate depends on local factors as well as the legitimacy conferred by the international community on divergent

[1] During the postwar period the number of central banks in the world almost tripled: from 49 in 1946, the number increased to 131 in 1975. Most of these were established in developing and post-colonial countries: 26 in sub-Saharan Africa, 18 in the Middle East and North Africa, 16 in Latin America, and 14 in East Asia and the Pacific. The rest were founded in South Asia and Europe. The dates of central bank inception are taken from (Pringle 2002).

policy instruments. The analysis is based on detailed research of the case of Israel, part of which is presented here, as well as on a comparative outlook.

20.2 Knowledge, Translation and the International Policy Discourse

Up to the present, most studies have described the process by which a large number of countries established central banks within the relatively short period of time following the Second World War as a case of temporal clustered policy reform (Elkins and Simmons 2005) accompanied by convergence. Two causal mechanisms have been suggested to explain this process. First, the symbolic mechanism assumes that newly established countries emulated industrial countries for the mere purpose of appearing to be like them (Helleiner 2003; Marcussen 2005). Central banks, which were symbols of independence, replaced the currency boards, colonial institutions that symbolized foreign control and oppression (Uche 1997). Another explanation suggests that developing countries established central banks because they sought monetary flexibility, a policy instrument that industrial countries possessed in the international monetary regime after World War II (Helleiner 2003).

Both causal explanations suggest that developing countries established central banks according to the northern, that is, the Keynesian model. Differences between northern and southern central banks, if at all apparent, are to be explained therefore in terms of 'decoupling' (Meyer et al. 1997) between functional and effective central banks originating in the North on the one hand, and poorly emulated and distorted central banks adopted in the South on the other. Decoupling and corrupted emulation are explained as 'biases' due to political constraints and "limitations in the learning process" which led to "inefficiencies" (Elkins and Simmons 2005, 45).

However, the divergence of central banking from the northern model in developing countries was not random as is implied by the notion of coupling. Rather, as we will see below, there was a pattern of regional convergence: northern countries converged around Keynesian central banking practices while southern countries converged around a unique type of central banking which I call *developmental central banking*. The existence of such a pattern of divergence implies that it was not a product of mere 'decoupling,' but rather a product of structural factors and coherent logic.

In order to identify these structural factors, it is necessary to abandon the 'point of view of the center' and to take the 'point of view of the periphery.' The 'center,' in this context is the place at which original practices and policies were produced and legitimized on the basis of standardized, codified and scientific knowledge. Taking 'the point of view of the center' is an epistemological position, which assumes that the policies justified by the institutionalized and standardized knowledge produced in the center are necessarily 'best practices,' irrespective of prevailing local conditions in the environment in which they are applied. Moreover, this approach assumes that the criteria used to evaluate these policies are universal and value free.

Taking the point of view of the periphery implies that observers historicize and endogenize the processes by which bodies of knowledge are produced, institutionalized, standardized, codified, transferred and translated. Such an approach underlines the *epistemic* dimension of the gap between the North and the South. According to our approach, peripheral countries, unlike core countries, do not possess the adequate resources to produce standardized, codified and institutionalized knowledge. Therefore, they lack the resources to justify and legitimize policies that deviate from internationally standardized policy models. 'Taking the point of view of the periphery' implies that observers refrain from evaluating the effectiveness of policies in the periphery on the basis of theoretical knowledge and criteria produced in the center. Instead they evaluate policies on the basis of outcomes and experimentation, while taking into consideration local goals, constraints, values and the uncertainty regarding the effectiveness of certain policies during the policy-making process.

This approach enables us to discern between cases of *decoupling* and cases of *translation* (Djelic and Sahlin-Andersson 2008). Translation is an intentional, calculated and institutional process of localization of knowledge and practices (Acharya 2004). In such cases, the imported policy instrument is not *corrupted* in the process of transfer, but rather is modified on the basis of local knowledge, experience, goals, values and constraints.

In this chapter, I argue that the establishment of the Bank of Israel (BoI) represents such a case of translation and that the main impetus to establish the institution was not symbolic or based on the need for monetary flexibility, but rather the solution of the local problem of allocation of credit. The case of the BoI shows that local policy makers resisted the symbolic pressure to establish a central bank during the first years following the establishment of the state in 1948. During this period, monetary flexibility was achieved by the establishment of the *issue department*. The issue department was a small department within the largest commercial bank in Israel, Bank Leumi. It lacked any capacity to resist the government's demands for loans. As long as it existed, the only limit to the government's monetary flexibility was its own responsibility for and acknowledgment of the long-term cost of inflation. During this period the government deferred the idea of establishing a central bank by claiming that the time "is not ripe"[2] and that "objectively this is not the time."[3] In the early years of the state, the national priority dictated the maintenance of monetary flexibility, even at the expense of the advantages associated with joining the International Monetary Fund (IMF) and improving access to foreign aid.

What tipped the balance in favor of a central bank, I argue, was the government's failure to solve a local problem in a closed policy domain: the problem

[2] Minutes of Parliament Sessions, Israel Parliament Archive, 9 July 1952, 2601.
[3] Minutes of Parliament Sessions, Israel Parliament Archive, 18 February 1952, 1340.

associated with the allocation of credit. From 1950 onwards, the government made several attempts to employ selective credit controls. Up until 1953, most of these attempts had failed (Bar-Yosef 1953, 1955, 1961). The supervisor of the banking system wrote, "the success of qualitative credit policies depends, first and foremost, on cooperation between credit institutions and the authorities" (Bar-Yosef 1953, 188). However, the government did not have the necessary legal and administrative resources needed to realign the interests of the commercial banks with the national priority. In 1953, policy makers within the government identified the opportunity to use the central bank in order to control the banking system and the allocation of credit.

20.3 The International Discourse and Regional Convergence

The question arises as to what the conditions were that facilitated Israeli policy makers to effectively translate the industrial or Keynesian model of central banking and to use it in order to allocate credit. Effective translation of policy practices at the state level requires more than a devoted individual. Its success is dependent on structural and institutional factors. In this chapter I discuss two of these factors. Domestically, the recipient state has to have a minimal capacity of calculation and sufficient agency. Internationally, the likelihood of effective translation depends on the *structure of the international policy discourse*.

For a developing country to translate the Keynesian model of central banking and use it to solve locally defined problems, it had to have a minimal capacity for calculation and sufficient agency to act according to the results of the calculation. Such an approach assumes, as Bennett and Howlett put it, that state actors "can learn from their experiences and that they can modify their present actions on the basis of their interpretation of how previous actions have fared in the past" (Bennett and Howlett 1992, 276). Or, as Hall formulates it, it implies that "elements within the state, acting, presumably, in pursuit of the national interest, decide what to do without serious opposition from external actors" (Hall 1993, 26). Calculation capacities and agency are necessary conditions to creatively adopt policy instruments while altering them.

The literature of social learning has studied these aspects extensively. However, it has not given sufficient attention to the discursive international conditions that affect the capacity of countries to translate policies and knowledge. The likelihood that an effective translation takes place hinges, among other things, on the relative legitimacy conferred by the international community on the divergent policy instrument. If the international community harshly delegitimizes any deviation from standard models, the adoption of a translated policy instrument would entail high costs. For example, foreign investors would divert their investments to other countries, and banks would increase the interest rates for loans. Therefore states would not be inclined to translate. On the contrary, if the international community acknowledges the principle that peripheral economies require deviant policy instruments, the cost of deviation would be reduced and states would be more likely to translate.

The *structure of the international policy discourse* is the variable that captures the extent to which the international community legitimizes (or delegitimizes) deviant policy models. A homogenous discourse that legitimizes a very narrow range of policy models and strongly delegitimizes deviant models creates strong incentives to emulate, and punishes those countries that adopt deviant models. In cases where the international policy discourse is heterogeneous, deviating practices are not delegitimized and policy makers in developing countries are more likely to translate standard models.

In the post-World War II period, as I show below, the international policy discourse of central banking was heterogeneous in the sense that reputable experts acknowledged the utility of developmental practices of central banking in developing countries.

20.4 The International Policy Discourse of Central Banking

When policy makers in Israel, as in other new countries, faced the question of establishing a central bank in the post-World War II period, there were three alternative models of central banking to consider, each of which possessed a differing level of legitimacy in the international policy discourse: the *traditional* British model, the *Keynesian* model which was promoted by the newly established IMF and the International Bank for Reconstruction and Development (IBRD) and, as I argue, the deviant *developmental* model.

The traditional model of central banking was shaped during the gold standard in the heyday of colonialism and a surging international trade (Gallarotti 1995; Eichengreen 1996). During that period, gold served as an international means of payment and central banks played a key role in stabilizing it by maintaining the convertibility between national currencies and gold within the member countries of the gold standard club (Gallarotti 1995). The principle of convertibility of currencies to gold and vice-versa was the anchor that guaranteed the stability of the value of national currencies at home and the stability of the exchange rates in the international arena (Capie et al. 1994, 10). Despite the image of the gold standard as an automatic mechanism, central banks played a guiding role in sustaining it by managing the demand for money and the international flow of capital through the use of interest rate policy and through the buying and selling of short-term bills (operations in the free market) (Sen 1952, 2).

During the interwar period, the Bank of London with the support of the League of Nations, the Bank of International Settlements and the Federal Reserves made attempts to restore the gold standard by globalizing it. It exerted pressure on the governments of developing countries to establish central banks that functioned according to the same principle as the British model in countries whose economies were radically different (Drake 1989; Marcussen 2005). In hindsight and from a domestic point of view, these central banks failed (Sen 1952).

In the colonial countries, imperial governments established *currency boards*, which extended the logic of gold standard to the periphery. Currency boards funtioned by converting domestic currencies to British currency, while keeping a 100% reserve ratio of British currency. Other imperial powers, like the US and France, enabled more discretion (Schwartz 1993). The strict British arrangement prioritized the stability and confidence of the domestic currency over monetary flexibility (Williamson 1995, 5–11).

After World War II the art of central banking went through a paradigmatic shift. The shift was a particular aspect of the emergence of the Keynesian paradigm (Hall 1989). Keynes rejected the view that business cycles could not be tamed. He suggested that appropriate fiscal and monetary policies could significantly increase the stability of capitalist markets (Barber 1990; Collins 1990). The new paradigm redefined the objective of central banks. Previously, the role of central banks had been defined very narrowly and technically as maintaining the stability of the value of money in relation to gold and to other currencies. After World War II the common conception was that central banks should pursue, in addition to stability, the objectives of growth and employment as well. The balance of power between central banks and treasuries shifted in favor of the latter. Monetary policy had to follow the lead of governments' fiscal policies (Cukierman et al. 1992; Eichengreen 1996, 94, 188).[4]

The instruments of central banks were also redefined. The incentive to use new instruments came from *below*, from practitioners of central banking, rather than from *above*, from economists. Due to the emergence of the welfare state, the growing size of public sectors and high taxation levels, the traditional instruments by which central banks used to influence the *demand* for money—interest rate policies and operation in the free market—lost their effectiveness (Sayers 1949, 1950, 1956; Brockie 1954; Miller 1956). Therefore, central banks turned to managing the *supply* of money. For this purpose a more stringent control of commercial banks was needed. In particular, the *reserve ratio* of commercial banks became a key policy instrument through which central banks controlled the supply of credit.[5] The new monetary instrument blurred the distinction between macroeconomic policies, aimed at managing macroeconomic variables on the one hand, and prudential policies, aimed at maintaining the stability of the banking system on the other (Capie et al. 1994, 25).

[4]Some historians reject this view and claim that in practice both fiscal and monetary policies were subject to the requirements of Bretton Woods-pegged exchange rates. The latter view implies that even during the postwar period central banks were actually seeking price stability (Capie et al. 1994, 1–2, 25).

[5]Reserve ratio is defined as the part of the banks' deposits that are kept in their vaults as reserves. An *increase* (decrease) of the reserve ratio implies *less* (more) credit to the market. Central banks could control the supply of money by determining and changing the reserve ratio that commercial banks had to maintain.

In developing countries the situation was different. Indeed, the shift from traditional to Keynesian central banking *favored* less developed countries as it acknowledged the legitimacy of governments to steer the economy in order to achieve locally defined goals such as employment and growth. However, the Keynesian paradigm assumed that the market was still the best mechanism for the allocation of resources through the price mechanism. In many developing countries markets existed in an underdeveloped form, and their performance was not consistent with the national priorities as conceived by local policy makers (Hunt 2002, 454). Specifically, governments in many developing countries sought to industrialize the economy in order to close the gap with the industrial world, or at least to minimize it. This goal required deeper intervention in the market and in the price mechanism. Keynesian economics as a rule, rejected this type of intervention.

In the financial domain, governments in developing countries employed various types of developmental instruments such as mobilizing savings, providing credit to developmental institutions and nurturing domestic public sectors. Central banks fulfilled a significant role in executing these policies (Hirschman and Rosa 1949; Brimmer 1971; Blackman 1979). In particular, developing countries employed *preferential credit policies*. The objective of such policies was to restrict the overall volume of credit and at the same time to channel cheap credit (with low interest rates) to nationally strategic industries and specific industrial projects. These policies required central banks to manage differential and multiple effective interest rates in the economy: low interest rates for industrial purposes and high interest rates for all other purposes (Wade 1990; Haggard et al. 1993). The effectiveness of such policies was dependent to a large extent on the bureaucratic capacities of the state. The fact that developing countries employed preferential policies has already been documented in the literature. This chapter makes the argument that the establishment of central banks in developing countries increased the administrative capacity of governments to implement these policies. This argument explains the incentive of local policy makers to establish central banks in the post-World War II era.

What distinguishes developmental from Keynesian central banking, therefore, is the consistent, continual, pervasive and premeditated use of selective credit instruments. Indeed, central banks in industrial countries also regulated the commercial banks, and some of their instruments—such as foreign exchange control—had selective side-effects on specific branches. However, in principle, most central banks in the industrial countries aimed at managing the *overall* supply of credit and were reluctant to execute multiple interest rate policies.

It should be pointed out that the selective credit policy was not an invention of developing countries. The Federal Reserve System (FED), for example, used credit control in a *negative* way, that is, it restricted the flow of credit to specific branches. France used selective credit policies quite extensively (Hirschman and Rosa 1949; Kriz 1951). It was left to developing countries "to carry this method of control to its conclusion." Central banks in developing countries were granted the authority "to exercise a general control over the lending policies of the commercial banks, including the power to restrict the grant of loans for particular purposes" (Sen 1952, 159).

20.5 The Worldwide Diffusion of Developmental Central Banking

When Israeli policy makers contemplated the idea of establishing a central bank, the British model of an independent and conservative central bank disintegrated and in addition to the orthodox Keynesian model, a new experimental model of developmental central banking began to emerge.

In Australia during World War II, selective practices were used. Initially, these were executed by a special governmental body, but later on, the Commonwealth Bank took charge of these policies. Similar measures were adopted by New Zealand, India and South Africa (Sen 1952, 160–162). The Central Bank of Sri Lanka similarly employed these measures: its Annual Report for 1950 states, "there was every indication that bankers were co-operating with the Central Bank's policy of restricting credit for non-essential purposes" (Shuv 2003, 67). The State Bank of India was formed in 1955 with the explicit aim to allocate more resources to selected sectors of the economy to facilitate economic growth and development (Capie et al. 1994, 214). Similar measures were adopted by the Bank of Greece (Capie et al. 1994, 194).

The large number of developing countries that adopted similar policy instruments supports the claim that the deviation from the standard model was a case of translation rather than decoupling. Nevertheless, it suggests that the process of translation was not carried out on an individual basis—by each developing country in isolation—but rather that there were channels which coordinated the process: American experts who had heterogeneous ideas regarding central banking in developing countries and south-to-south transfer of knowledge.

20.5.1 American Experts

When the Israeli government took the decision to establish a central bank, it sought American advisors. Arthur Bloomfield was one of them. He was one of the experts to advise Israeli experts and politicians on how to formulate the central bank bill; he fulfilled a key role as a mediator between the international policy discourse and the Israeli experts. Bloomfield was a research economist at the Federal Reserve Bank of New York. In the late 1940s and early 1950s, he was sent to East Asian and Latin American countries to give advice on their central banks and financial systems (Alacevich and Asso 2007). This type of job—money doctoring—situated Bloomfield in a strategic cross section of the processes of translation of policies. He played the role of mediator between the standardized principles of central banking and the unique conditions in developing countries.

As an American expert, Bloomfield was able to legitimize developmental central banking. In his missions Bloomfield insisted on taking into account the uniqueness of the economic condition of the countries in which he assisted the local authorities in establishing a central bank. He confronted other experts who, in his view, neglected the significance of such differences. The deviation of Bloomfield's views from the orthodoxy was manifested in his exchange with the director of the research department at the IMF, Edward Bernstein. In the case of the Philippines, Bloomfield criticized Bernstein's approach as being "too broad and general, and insufficiently oriented around Philippine problems." He referred specifically to the lack of any reference by Bernstein to selective credit policies (Bloomfield 1955).

Bloomfield publicly defended the notion that there was a theoretical justification for the use of alternative policy measures in developing countries, or at least that there was no theoretical foundation to the claim that such measures are ineffective. Central banks in developing countries, he wrote in an article, used measures that were "admittedly outside the traditional scope of central banking." Moreover, the deviation of these instruments from traditional central banking did not render them ineffective. "Central banking in these countries should not necessarily be evaluated in terms of the standards and criteria applied in the more developed ones." As the practices of central banking in developing countries had not emerged from a fully-fledged theory, Bloomfield characterized them as "experimental." He expressed the hope that "out of this experimentation will develop a theory of central banking policy appropriate to the economically backward countries" (Bloomfield 1957, 204).

Bloomfield was not unique in these views. An official report made by the Federal Reserve Bank of New York about central banking in developing countries recognized the utility of such measures, although it qualified their applicability by stating that their effectiveness is dependent on "the prestige and stature that the central bank enjoys within the financial community and the public at large" (Fousek 1957, 78). Thus, although developmental central banking did not enjoy the international legitimacy of Keynesian central banking, it was not rejected out of hand by the international policy discourse of central banking. The existence of two legitimized models of central banking played an enabling role regarding the process of translation. Policy makers in developing countries were almost encouraged to treat the Keynesian model as a starting, rather than the end point, of the policy transfer process.

Contrary to the underlying assumption of the *flat* view of globalization which assumes the prevalance of a *homogeneous* international policy discourse leading to convergence, it is assumed here that the international policy discourse, in certain policy domains, can be *heterogeneous*. It may consist of more than one legitimate policy model and therefore its diffusion is likely to lead to divergence and regional convergence rather than global convergence. This was the case in the policy domain of central banking in the post-World War II period.

A heterogeneous structure of the policy discourse is the outcome of internal debates and disagreements within the international epistemic community. When members of an epistemic community do not reach a consensus regarding the best practices in a policy domain, more than one policy instrument would be legitimized for use by different countries. Such was the case in the international policy discourse of central banking in the post-colonial period.

20.5.2 South-to-South Policy Transfer

The structure of the international policy discourse was not only the product of epistemic communities located in the core countries: policy makers and experts from peripheral countries also had the capacity to affect it. After World War II, developing countries joined the international community and participated in international organizations such as the IMF, the World Bank (WB or IBRD) and the United Nations (UN). The international organizations served as key channels for the south-to-south transfer of knowledge and policies. In such a process, peripheral countries, instead of looking up to industrial countries, "have the choice of looking to other developing nations for programmes" (Rose 1991, 14). The structural similarities amongst peripheral countries increased the likelihood of an effective transfer of policies, despite the fact that the policy instruments did not enjoy the same legitimacy as those used by industrial countries.

The IMF and the World Bank were two nodal points in an international network that connected industrial and developing countries and they faciliated the exchange of knowledge. In this network, knowledge flowed in all directions, essentially, from north to south (Barnett and Finnemore 2004). But the annual meetings of these organizations, however, also served as spaces in which ideas spread among developing countries who shared their experience with unique instruments such as preferential credit policies. As the governor of the BoI announced at the IMF's annual meeting in 1960, "qualitative control of credit is an imperative in order to achieve selectivity in investment and a proper order of priorities with a view to improve as rapidly as possible the balance of payment of the country" (Horowitz 1960). The *U.N. Economic Commission for Latin America* (CEPAL) established in 1948, and the *U.N. Conference on Trade and Development* (UNCTAD), gave rise to a translational epistemic community comprising local experts and policy makers who exchanged knowledge and ideas about developmental practices (Sikkink 1991, 55).

20.5.3 Local Problem-Solving Through Translation

The structure of the international policy discourse and the legitimacy conferred on developmental central banking practices by American experts and international organizations played an *enabling* role in the process of translation. However, the positive incentive to establish central banks in developing countries, I argue, was the product of a common-domestic problem: credit allocation.

Prior to the establishment of the BoI, the government used its regulatory powers as laid down by the Banking Act in order to force commercial banks to cooperate with the selective credit policy. In addition, the government exerted informal pressure on the directors of large banks through the Banking Committee, a body comprised of the directors of large banks and a government representative (Bar-Yosef 1953). However, until the establishment of the central bank, the government enjoyed only partial success in enforcing its will on the commercial banks.[6]

In 1953 the Minister of Agriculture managed to convince several commercial banks to cooperate with the government to create cheap long-term credit for agriculture. Commercial banks committed to channel 20% of their credit to agriculture with government collateral.[7] His experience negotiating with commercial banks on credit allocation convinced the Minister of Agriculture that a better solution to the problem of credit had to be found.

The Minister of Agriculture, the main figure involved in negotiations with the commercial banks regarding the allocation of credit, was also the one who urged the government to hasten the process of establishing a central bank. "We have to reach a decision whether the thing is important or not" he insisted,[8] emphasizing that a central bank would be "an instrument of credit control."[9]

The government reached a decision to hasten the process of establishing a central bank. It was in this context that establishing a central bank turned out to be a solution to the local problem of allocation of credit as well as a response to the external soft pressure to establish a central bank. A delegation was sent to negotiate with the IMF regarding conditions for Israel's membership. The IMF promised that other than "persuasion" no restrictions or pressures would be exerted.[10] At the end of the year the government nominated David Horowitz as governor of the Bank, and, one year later in December 1954, the BoI was officially inaugurated.

20.6 Mutual Interdependence Between the Government and the BoI

The BoI was a hybrid of a Keynesian central bank with some modifications which endowed it with the capacity to function as a powerful instrument for allocating credit. Local policy makers and experts were convinced that this kind of instrument would serve the national interests and goals more effectively than a standard—Keynesian—central bank.

So far I have attempted to explain the considerations which, given the national goals and local economic conditions, led local policy makers to *translate* the central bank rather than *adopt* it. However, the question arises as to why policy makers could not solve the local problem of credit allocation with original institutional innovation. In other words: why it was cheaper to *translate* rather than

[6]Minutes of the Banking Committee, Israeli State Archive, 5617/2 Gimel, 23 August 1953, 26 January 1954, 14 April 1954.
[7]Minutes of Government Meeting, Israel State Archive, 12 May 1954, 15.
[8]Minutes of Government Meeting, Israel State Archive, 8 February 1953, 10–11.
[9]Minutes of Government Meeting, Israel State Archive, 12 May 1954, 14.
[10]Minutes of the Finance Committee, Israeli Parliament Archive, 1 November 1953, 6.

to *innovate*? To answer this question we need a more detailed analysis of those elements of the central bank that were adopted and those that were translated.

According to the literature, the origin of central banking during the financial revolution in England was based on the institutional innovation of "credible commitment" (Williamson 1975) or "commitment through delegation" (Cukierman 1994). The underlying principle suggests that governments committed themselves to respect private property rights and to avoid confiscation (or writing off loans) by delegating power to an *independent* institution which functioned according to constitutional rules and professional standards (Cukierman 1994). The commitment of the government increased the confidence of capital owners in the government and reduced the risk premium associated with loans to the sovereign. Therefore, the innovation of independent central banks was associated with the protection of nascent market economies from the unpredictability of sovereign power. The sovereign relinquished their authority to nationalize private property and in exchange gained the capacity to raise cheap credit. Sociologists and political scientists would describe this development—following Weber—as a particular case of the emergence of the modern apolitical bureaucracy (Weber 1965).

The principle of credible commitment and the concept of central bank independence were products of the codification and standardization of central banking practices in industrial countries. It was formulated under the assumption that a differentiation between states and markets and the protection of the latter from the intervention of the former was a necessary condition for sustainable economic growth.

However, during late industrialization, the protection of markets from the state was not a sufficient condition for development (Gerschenkron 1962; Hirschman 1981). A distinction has to be made between the late industrialization of Europe in the nineteenth century and the industrialization of peripheral countries in the mid-twentieth century. France and Germany employed different strategies to industrialize the economy. In France the state functioned as both actor and planner (Kriz 1951), while in Germany the state provided the infrastructure for the emergence of an oligopolistic market-economy (Henderson 1975). However, in both cases, developed legal and bureaucratic infrastructure existed in which economic development was embedded. Contrary to the European countries, in the developing peripheral countries, an infrastructure did not exist. Therefore, many of the new states that were established in the 1950s and the 1960s were in a deadlock: on the one hand, they did not possess markets and entrepreneurial forces to drive their economies forward; on the other hand, they did not have the institutional capacity to take charge of the economy and manage it with a top-down approach.

The strategies of rapid industrialization required unique state capacities as governments had to confront powerful societal actors as well as market forces (Wade 1990; Weiss 1998). These strategies thus necessitated considerable administrative, bureaucratic and institutional resources (Evans 1995; Woo-Cumings 1999). In particular, they required the capacity of the state to control and manage the financial sector in order to channel credit to preferential purposes (Zysman 1984; Haggard et al. 1993). Most of the new states lacked such capacities and resources, and the establishment of central banks provided an opportunity to acquire them.

The establishment of central banks, I argue, provided an opportunity for new states to fortify their administrative and legal infrastructures in the financial domain in order to better govern their economies. Central banks functioned as a stronghold of domestic power that provided legitimacy and administrative resources in order to pursue industrialization. As was the case in industrial countries, central banks enjoyed the status of professional and apolitical institutions which were relatively autonomous of both party politics and the socio-economic domestic dynamics. However, unlike the central banks in industrial countries, their purpose was not to protect markets from the state, but rather to serve as an instrument to confront societal actors and to govern the market.

Developing countries lacked the resources that were required for purely local institutional innovation. They lack the experience, the know-how and the skilled personnel necessary to solve local technical problems, as well as the legitimacy and the necessary legal infrastructure for its effective implementation. Imported models can solve both problems: they are accompanied by technical and administrative aid and training programs that enhance the administrative capacities of governments. Moreover, imported models are endowed with international legitimacy (Graziadei 2006; Watson 1974). In short, imported models have the advantage of providing local authorities with the administrative and legal resources that contributed to the capacity of government to confront local actors.

The translation of standardized policy models and institutions therefore enables local policy makers to enjoy—to some extent—the best of both worlds: unlike simple adaptation, translation takes into account local knowledge and contingencies; unlike pure local innovation, they are administratively, politically and economically cheaper to implement.

This mechanism can explain the coupling between the institutional units of the central bank and the exercising of selective credit policies: it was more effective and cheaper for governments of developing countries to employ these policies through an apolitical, relatively autonomous institution, which enjoyed international legitimacy, than to carry out this policy themselves.

The case of the BoI demonstrates this point. Its establishment contributed to the capacity of the state in several ways. Prior to the establishment of the BoI, monetary and supervisory powers were scattered among a number of different governmental bodies. In addition, five bodies were involved in managing the issues that later on were managed by the bank. The issue of money had to be approved by the finance committee and by parliament. The technical aspects of issuing money were taken care of by a special department within Bank Leumi (the *issuance department*). The supervision and regulation of the banking system was dealt with by a special department within the Ministry of Finance. With the establishment of the BoI, all these issues and powers moved to the central bank.

From the point of view of the state's capacity to govern, such a centralization of powers had several advantages. As Zysman points out, the centralization of power, "enables a single agency to exert influence across a range of issues without having to develop regulatory or administrative apparatus for each specific case." Moreover, such "multipurpose policy tool is outside the direct control of the legislature" (Zysman 1984, 77).

The authority of the BoI was derived largely from its role as mediator between the government and the two major international financial institutions, the IMF and the IBRD. International organizations exerted strong influence over policy-making on a state level (Barnett and Finnemore 2004). The influence of the global organizations is based on the flow of expertise, knowledge and data to other countries (Stone 2004, 554). Moreover, they had leverage on countries due to the financial aid programs (Lal 2001). The power, the relative autonomy and the legitimacy of the international organizations were conferred institutionally and symbolically on central banks as *representatives* of the international organization in the public arena. Moreover, central banks also represented the country in its contacts with the international organizations. The mediatory role of the central bank contributed to its informal authority and legitimacy in the local arena.

These features were pertinent to the case of Israel. According to the Central Bank Bill, one of the BoI's roles was to act on behalf of the government as a member of the IMF and the IBRD.[11] The BoI therefore maintained continuous contact with the IMF and the IBRD, which in turn supplied it with knowledge and expertise in various forms. The BoI's governor also used IMF publications, which emphasised the main goal of the BoI—price stability—as an important condition of sustainable economic development in order to augment his own persuasive powers (Horowitz 1975). The prestige of the international financial institutions was therefore conferred on the BoI and it increased its influence in the local arena.

The BoI's persuasive power was further ameliorated by its capacity to generate economic data, knowledge, analyses and forecasts relating to the Israeli economy. This was necessary to identify problems, to formulate goals, to assemble policies and programs and to implement them, and in addition, it was essential to mobilize support for programs and to legitimize them. The research department of the BoI was the only source of empirical economic knowledge that encompassed the whole economy. Its Annual Report provided an essential source of information and analyses in the Israeli economic discourse. The department maintained contact with prestigious foreign economists and institutions, a practice that kept it up-to-date and contributed to its professional prestige (Gross 2007, 181–185). The BoI's capacity to produce empirically-based and up-to-date theoretical knowledge was an extremely significant factor in its ability to present as non-political its analyses, recommendations and policies.

Due to its autonomous budget and unique terms of employment the BoI also provided an opportunity to improve the meritocratic recruitment of personnel.

[11] The Central Bank Bill, 1954, Article 71.

The budget was managed by the bank itself, as was the employees' pay scale. The budgetary independence of a central bank is an index of its actual independence (Cukierman et al. 1992, 366, table 4). As it offered employment conditions that were unprecedented in the public sector, the BoI managed to attract high-quality staff, including the leading graduates from the Hebrew University's Economic Department. This was one of Weber's conditions for effective state power and autonomy (Evans and Rauch 1999, 751, Weber 2009, 241). As a result, the BoI nurtured an autonomous community of economic experts speaking one language, a phenomenon that enhanced its image of objectivity and professionalism.

With the establishment of the BoI, many powers that previously had been dispersed among several other authorities and institutions were transferred to the bank. The centralization of power increased its "coherence and corporate identity," which in turn increased its capacity (Evans 1989, 573). As Johnson points out in his classic study about the Japanese developmental state, its capacity relied to a large extent on the existence of an informal network of experts who graduated from elite universities in Japan (Johnson 1982, 57–59). In the case of Israel, a young state, a network of elites did not exist and the BoI contributed to the consolidation of such a network.

The institutional unit of the central bank was thus imported and it provided further capacities for local policy makers. However, while in the industrial world the autonomy of central banks restricted the legitimacy of the government to manage the economy, in developing countries the apolitical status of the central bank and its professional status were used in order to control, restrain and mobilize local societal actors.

20.7 Conclusions

In this chapter I have discussed the epistemic and institutional aspects of the translation of central banking to peripheral countries in the post-World War II period. The analysis suggests a few directions for generalization and for further research.

The post-World War II period was a unique period in terms of cross-country transfer of economic knowledge and policies. During this period the international community became more heterogeneous than in any other period since the emergence of the international system in the seventeenth century. From the four nations that constituted the Concert of Europe in the nineteenth century and around sixty members who were involved in the League of Nations in the interwar period, the number of member nations in the UN reached 140 in the 1970s. The majority of the new countries did not have developed markets or industrial infrastructures and their socio-economic structures differed radically from those in the industrial world. While those countries possessed nominal sovereignty and were *equal* members in the international community, as far as their structure was concerned, they were essentially different. Therefore, it is justifiable to argue that the community of nations became highly heterogeneous from a structural point of view.

The heterogeneity of the international system posed an unprecedented challenge to macroeconomics, a body of knowledge whose primary object was national economies: on the one hand, as a standardized, codified and theoretical body of knowledge the macroeconomic discourse assumed—and it had to assume—a certain level of "homogeneity of nature," that is, a "spatial and temporal permanence of general laws" (Desrosières 1998, 282). It had to assume that despite differences between national economies, there are essential structural similarities that made comparisons justifiable. One fundamental similarity was the epistemic condition of macroeconomics, just as the epistemic condition of biology is that all individuals within a species are essentially similar; on the other hand, empirically, the institutional, social and economic differences between national economies were enormous.

The challenge was aggravated by the fact that it had not only theoretical but also practical implications. The policies that were formulated on the basis of macroeconomic knowledge affected international politics and the lives of millions. It is beyond the scope of this contribution to discuss the ways in which macroeconomics dealt with this challenge. However, we can draw several generalizations on the basis of the policy domain of central banking.

During the interwar period, the Bank of England, with the support of the League of Nations, the Federal Reserve and the Bank for International Settlements, made a concerted effort to export the British model of central banking to Latin American countries (Drake 1989). The mission of globalizing the gold standard and central banking practices was obviously driven by UK interests. The UK, which based its power on international trade, had a clear interest in the maintenance of a stable international means of payment. However, the drive to restore the gold standard was also the product of a stiff policy paradigm that prevailed amongst UK civil servants. The British bureaucracy was very closed, hierarchical and immune to change (Weir 1989). Moreover, until the 1930s, there was no alternative policy paradigm to the one promoted by British policy makers. It took some time until the Keynesian alternative permeated the inner circle of the British state apparatus (Weir and Skocpol 1985; Weir 1989).

Similarly, in the neoliberal period during the 1980s and 1990s, national interests were combined with epistemic factors. In the 1980s after the oil price crisis and the international debt crises, the IMF began to implement the Structural Adjustment Programs which conditioned financial support by domestic reforms (Goldstein 2001; Drazen 2002; Khan and Sharma 2003; Akonor 2006). Among other requirements, developing countries had to reform their central banks' bills and upgrade their independence vis-à-vis governments (Polillo and Guillén 2005).

The ambition to coerce central banking reforms was supported by newly formulated theories of central bank impendence. Academic economists demonstrated, on the basis of the principle of rational expectation, that high central bank independence was essential to curb inflation (Barro 1976; Barro and Gordon 1984). The theory was supported by evidence regarding the correlation between a high level of independence and low inflation and growth (Berger et al. 2001). This conception dominated the international policy discourse throughout the 1990s and the 2000s.

The Bretton Woods period was unique in the sense that the combination of geopolitical constellation, on the one hand, and the heterogeneous structure of the policy discourse on the other, played a permissible role in regard to acts of translation. One could not escape the question, though, of whether the structure of the international policy discourse was not only an epiphenomenon of the geopolitical constellation. Helleiner, for example, explains that:

> The sympathy that U.S. officials exhibited towards the nationalist monetary goals of Southern governments often reflected their desire not to alienate key allies in the context of the Second World War and then the Cold War. It also helped them to gain influence in newly independent Southern Countries, particularity ex-British colonies. (Helleiner 2003, 268)

It is undeniable that the geopolitical conditions and the national interest of world leaders influenced, to a certain extent, the openness of experts to the idea that deviant models were effective in a heterogeneous world. However, the transmission mechanism between national interests and the international policy discourse is not that simple. If it were, we would expect that during the post-World War II period the *dominant* view among American experts would support deviant models of central banking in developing countries. In practice, this was not the case. Rather, the American discourse of central banking was characterized by *heterogeneity*, that is, by internal disagreements and debates among experts. The heterogeneity of the discourse cannot be explained on the basis of political influence. Therefore, we may conclude that the view of experts was not completely determined by the national interests of the country they served and that there was uncertainty among experts regarding the best practices that suited developing countries.

According to this line of reasoning, what was unique in the policy discourse during the Bretton Woods period was not only the fact that it consisted of Keynesian ideas, rather than, for example, laissez-faire or liberal ideas. No less important was the fact that the policy paradigm was flexible and heterogeneous enough to embrace a wide range of policy instruments. Keynesian ideas were interpreted in various and very different ways. Some, like the neo-Keynesians, concluded from Keynesian economics very conservative policies, while others interpreted Keynesian economics as conforming to the principle of social democracy (Hunt 2002). Keynes, some argue, was even a source of inspiration to developmental economics (Toye 2006). The heterogeneity of the discourse, I argue, affected the capacity of local policy makers to translate and localize economic knowledge and policies.

It has already been established by various authors that globalization processes do not lead to a demise of the state (Weiss 1998; Sassen 1999; Polillo and Guillén 2005) nor to global convergence (Radaelli 2005). However, there is still much to be studied regarding the transmission mechanisms that translate global pressures to domestic actions. Bodies of knowledge, and particularly bodies of policy-relevant bodies of knowledge play an essential and significant part in these mechanisms. The international policy discourse and its structure play a crucial role in such a transmission mechanism.

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Chapter 21
On Juridico-Political Foundations of Meta-Codes

Richard Rottenburg

21.1 Introduction

This contribution *aims* to downscale the macroscopic focus on the encounter between culturally specific knowledge and globalized knowledge to a microscopic and ethnographic focus on *knowledge practices* of actual encounters and negotiations. The emphasis is on practical knowledge dealing with techno-scientific solutions that normally emerge as globalized knowledge. As is customary in microscopic analysis, this study follows the extended, theoretically guided case method and examines large issues in small places. The small places in this research are single planned interventions (mostly) situated in African countries and at the same time embedded in global organizational fields that generate various forms of globalized knowledge. The large issue in this research is the enunciation of rationality and standards of objectivity that are considered to be valid in different conceptual schemes and can therefore travel as models for doing things. I will argue that practitioners acting in epistemologically heterogeneous fields normally develop a specific form of meta-knowledge that enables them to move back and forth between two different forms of knowing that become labeled as culturally specific knowledge and globalized knowledge. I will examine and explicate these two forms as well as the reflexive competence to move back and forth between them; this competence I call *code-switching*.

In developing this argument, I rely on the basic assumption that the key form of knowledge diffusion is *translation* in the sense that without translation an idea loses its meaning on its travels from one conceptual scheme to the other and is essentially lost (Rottenburg 2003, 2009). In everyday modern English, *transfer* refers to an operation where a thing or token is moved from one context to the other without distortion, while *translation* refers to a similar operation where the thing or the token is changed in order to make sense and be useful in the new context. In classical Latin, though, *latum* is the perfect passive participle of *ferre*, and hence *translatio* is a nominal form derived from the perfect passive participle of *transferre*. The emerging field of a *sociology of translation*[1] uses translation as an aspect of transfer: transfer does not work without translation. In order to travel, ideas first have to be objectified into mobile objects, that is,

[1] See (Callon 1986; Latour 1995; Heilbron 1999; Rottenburg 2009).

translated into immutable mobiles. These objects are primarily texts, numeric expressions, tales, pictures, musical patterns, models for doing things with their implied rationality and ontology, and technical artifacts. Going on a journey means that the objectified ideas, the immutable mobile objects, are removed from their context and thus disembedded. Sent or brought to new places, they become re-embedded into another context, that is, into another institutional order, another material set-up and perhaps another epistemic order. Not every diffusion is at the same time a translation; a translation has happened and can be identified if the transferred idea (inscribed into an object) connects to the new web of belief, institutional order and material set-up and is thus put into new actions with a new and specific dynamic that was not there before the translation. If these patterned actions are repeated often enough, they might stabilize into a routine practice, that is, an institution as a set of unquestioned rules that eventually appear *natural*. The institution, in turn, will sooner or later be described and summarized through abstract ideas, which might start a new translation chain—and so on for ever.

At the same time, in developing this argument, I critically follow an approach proposed by Mary Douglas and Aaron Wildavsky in their book *Risk and Culture. An Essay on the Selection of Technical and Environmental Dangers*. Their work is on risk and pursues the question of how people agree to ignore most of the potential dangers that surround them and interact in a way as to concentrate only on selected aspects (Douglas and Wildavsky 1982, 9). The basic assumption of their analysis is that no amount of additional, scientifically based knowledge can provide an unchallenged ranking of dangers or an undisputed definition of what an appropriate prevention would be. The situation is even more complicated if one considers the fact that normally it is different kinds of people who have to agree on specific risk prevention measures, and different people normally find different kinds of risks more or less acceptable. The clue is that knowledge—as denotative descriptions of what the world is like—is here inextricably interwoven with consent—as evaluative and moral statements about how to live. Risk therefore should be seen as a joint product of knowledge about the future and consent about the most desired prospects (Douglas and Wildavsky 1982, 5). According to Douglas and Wildavsky, an appropriate understanding of risk selection therefore implies what they call cultural analysis. They intend to demonstrate that each set of shared values and supporting social institutions is biased toward highlighting certain risks and downplaying others—this being one of several forms of cultural bias (Douglas and Wildavsky 1982, 14).

While I partly follow this approach, my argumentation deviates from the implied epistemological position in four important regards. It is helpful to enumerate these four points since they help to clarify my own approach.

1. Empirically speaking, I do not focus specifically on risk but more generally on what are considered environmental, medical, economic, social, and political problems and their solutions—solutions that in the end might turn out, or not, to be risky or straightforward harmful (Edelman 1988).

2. I do not concentrate on negotiations within 'one society'—as Douglas and Wildavsky would have it—but on negotiations that take place in between cultures, or, as I would rather call it, in *heterogeneous trading zones*—to re-import an old anthropological metaphor back from Science and Technology Studies (Galison 1997, 781–844).
3. Within these intermediate fields I concentrate on how certain knowledge forms are turned into global knowledge by being attributed universal validity while other forms are turned into local knowledge. I hence do not start from a given distinction between local and global knowledge that would be founded in the range of validity of that knowledge. Instead I rather analyze how this distinction is made in one particular context.
4. I do not use culture (or society) as *explanans* of certain puzzling practices but rather as *explanandum.* Other than Douglas and Wildavsky—who present a fine piece of institutional sociology of knowledge—I follow a post-Mertonian microscopic, social constructivist approach to techno-scientific practices. In doing so, I examine the practices of defining and classifying problems and their solutions as a reality *sui generis*, that is, as a reality that cannot be conceived as a mere epiphenomenon completely determined by cultural or other patterns.

In more detail, this chapter focuses on an aspect of planned interventions that can be described as a particular form of *experimentation* performed in a particular form of laboratory known as pilot project. Like laboratories, pilot projects and urgent humanitarian interventions are demarcated exterritorial sites where people experiment with prepared segments of reality and produce reconfigurations of the natural order in relation to the social order (Knorr-Cetina 1999). Pilot projects and humanitarian interventions have *ex ante* defined goals and *ex ante* defined criteria for verifying the achievement or failure of these goals; they rely on collective action normally characterized by an antecedent agreement that all parties involved participate out of their free will, and that all decisions are taken in consenting manner only. Normally there are three parties involved: a financier, a consultant, and a project agency that is the target of the intervention and at the same time in charge of it. In nearly all cases, the financier and the project agency do not deal in their own name but as representatives of larger units (like for instance a ministry or an international agency). By definition, development projects and humanitarian interventions operate with money that belongs to none of the parties involved, and usually it is grants or cheap money.

The individual and collective actors of pilot projects and humanitarian interventions typically come from different cultural and professional backgrounds yet at the same time—at least, if long enough in the business—they belong to a global community of professionals with a highly specialized corpus of expert knowledge. This community has evolved since the 1960s (the beginning of development policy) and its members are mostly engineers, agronomists, medical specialists, economists, lawyers, and social scientists. In the meantime it seems appropriate to speak of an *epistemic community* (Haas 1992). Yet at the same time, projects and humanitarian interventions are archetypal cases exemplifying what is called *distributed agency* (Garud and Karnøe 2003). While the actors running a development project or a humanitarian intervention can be identified and also a number of liabilities are clearly defined, the agency is distributed far beyond the boundaries of the intervention.

21.2 The Case Study

The empirical focus of this chapter's argument is an ethnographic case study (conducted between 1992 and 1998) of the organizational and technological improvement of the waterworks of three cities in Tanzania (Arusha, Moshi and Tanga).[2] The project under scrutiny was financed by the German Development Bank (KfW) and one of the main areas the book covers is the relationship between the bank as a donor and manager of development aid and events as they unfold between various sites in Tanzania, Germany, and other countries as the water system is managed.

Development cooperation is about the transfer of resources from the rich countries of the North to the poor countries of the South according to political priorities. In order to be legitimate within the rich countries, this transfer has to be made in ways that can be accounted for and therefore must appear predictable. In order to secure this accountability and predictability, the resources—money, technology, and know-how—cannot simply be handed over as means to achieve any ends that are to be chosen freely by the recipients. The resources rather have to be invested according to criteria and protocols that are sound for all parties involved and thus have to follow principles that are internationally approved by legitimate bodies and carry the label of *state-of-the-art*.[3]

The conditionalities and prescriptions coming along with transferred resources are also due to another, more fundamental reason. The transferred means are unavoidably linked to certain ways of doing things and have certain ends built into them that necessarily become transferred with the means. The implied rationalities as relations between means and ends are based on basic assumptions about society, the individual, the natural world and the norms and values to be achieved. Development interventions therefore always aim at a more or less fundamental transformation of the institutional set-up of the context that is targeted. A short explanation of this point helps to introduce the case study. The larger part of development aid money goes into infrastructure projects that are conceived to be primarily technological affairs—mostly transport, communication, and power—with at most some minor socio-political and juridical implications. However, infrastructures are large technical systems with an inbuilt rationality

[2]Taken from (Rottenburg 2009).

[3]This is a complex argument highly relevant for the hypothesis supported here, yet it needs another full paper to be presented, cf. (Rottenburg 2000).

or, as one should rather say, an inbuilt cultural bias, that is, organizational and juridical dimensions with deep implications and far-reaching consequences.

In my case study, improving the water supply of urban centers in Tanzania was first seen as a matter of *pipes and pumps*. In the 1970s the population growth of Tanzanian towns “gave rise to” an increasingly serious water shortage. The logic applied by all parties concerned was this: if there is not enough drinking water, we must produce more. With the help of a German development project the city of Arusha was equipped with sufficient ground water pumps in order to supply the whole urban population with clean drinking water. It then turned out that the amount of water lost through leakages in the distribution system was so high that the effect of the investment was substantially reduced. In a second project phase realized in the 1980s most of the leakages were repaired. In the 1990s the city of Arusha approached the German Bank for Reconstruction and Development with a new project proposal based on the finding that the city still did not have enough water. In the meantime, though, development policy was geared around structural adjustment programs which put another question first, namely: who pays for this water? While the Tanzanian experts still argued with the rhetoric of “not enough water for the poor people,” their German counterparts had switched to the question of the economic viability of the waterworks. Further investments into hardware (like pumps and pipes and so forth) were made conditional on certain organizational improvements of which the key point was economic viability. The water utility of Arusha had to prove that it sold its services to its customers for an appropriate price, that it uses its income to maintain and improve its services and infrastructure, and that all this would be sustainable.

Lengthy negotiations resulted in another new project, this time explicitly restricted to organizational improvement. In the course of this project it turned out that changes in the organization depended on the Civil Servants Act, the Water Utilization Act, the River Basin Management Act agreed upon with the neighboring countries, the regulation of competences between central and regional government and municipality, the Citizens’ Registration Act, and on many more juristic regulations of governance. Like the famous airplane that cannot fly with just a pilot in it, a water production and distribution system does not provide water with just a chief mechanic operating the main valve.

There are, in other words, two main reasons why transformations caused by development interventions are heavily influenced by those who offer aid for this purpose, namely accountability and the cultural bias inscribed in technologies. While this is unavoidable, it runs head-on against one of the most important official political goals, namely to facilitate self-determined development on the side of the recipients of aid. Since there is no plain solution to this aporia between, on the one hand, accountability and predictability and, on the other hand, self-determination, the participants in this game have to circumvent it by all means in order to keep their business going. They proclaim that the means they transfer through development projects—like for instance technical infrastructure—are independent of any goals, are universally given, and based on objective facts. The goals admittedly depend on value decisions. Yet, as is officially stated, democracy, good-governance, human rights, market economy, and welfare for a maximum of people are general human goals independent of cultural variations. The role of so-called *cultural factors* in development is relegated to other and minor issues as long as they do not challenge the key assumptions of those general goals. The politically sensitive topic of true cultural heterogeneity[4] among partners in development is avoided at all costs—like for instance anything that challenges the Western perception of the individual as an independent entity geared to choose between options and to take free, rational decisions for its own benefit (Hacking 1986). If true cultural heterogeneity occasionally surfaces due to imprudent behavior within the community of experts, the unlucky proponents are ostracized for ethnocentrism, Orientalism or "othering."

As a result of the circumvention strategy around the aporia between predictability and self-determination and against the (since the 1980s) official rhetoric of a culturally sensitive development policy, development cooperation is essentially carried out as a *technical game*. This game is perceived to be independent of social and cultural frames of reference, and it is primarily about optimizing effectiveness and efficiency (and therefore less about truth, goodness, and beauty). This—most importantly—reinforces the initial assumption (see above) that technology and social techniques (like commercial accounting, incentive programs, etc.) are free of any cultural bias. The ends and the protocols inscribed into technologies—that is their cultural imprints—remain black-boxed.

With my research I try to show that the technical game normally assumed to be the lowest denominator for cooperation turns out to be at the same time the main cause of its failure. While the argument about the inbuilt failure is similarly made by others,[5] I depart from the interpretation that in the end the failure is due to politics, power asymmetries, hegemony, or other reasons that could be avoided under fairer circumstances and other forms of domination. The technical game—this is my argument—is unavoidable for socio-epistemological reasons given in the nature of epistemologically heterogeneous zones and it inevitably has some iatrogenic effects. Accepting this might increase the level of reflexivity and shift the attention to questions of how to improve the technical game instead of denouncing and demonizing it while dreaming of an ideal world where social arrangements can be changed toward more equality and justice without any damage.

21.3 The Main Hypothesis

On a general and abstract level, the central concern of my argument is with the production of facts through technologies of representation and inscription. It helps to first mention the practical problem at hand in the field in order to get down

[4]That is alienity, see (Rottenburg 2006).
[5]Cf. (Ferguson 1990; Escobar 1995; Mosse 2005; Li 2007).

to a more concrete level of the concern. The day-to-day management of the water systems to be improved by the pilot project under scrutiny critically depends on technical tasks such as mapping and building databases. Without an adequate database (how many customers there are, how they are distributed over the territory covered, where the distribution endpoints are located, and so on) the system cannot be managed effectively. Without effective management it cannot generate the income needed to maintain it. Without system maintenance the development aid used to finance the technological system becomes meaningless as the system will not work. The work of territory mapping and database building involves the representation of an external reality by technologies of inscription. These sophisticated cultural techniques—i.e. mapping and systematic storage of data—turn out to be the essential challenges of an intervention that started undemandingly as the transfer of *pipes and pumps* and the implementation of a simple organizational model.

This argument implies that the question of which *technologies* are more or less appropriate for developing countries—a question at the heart of development aid debates for decades—cannot be separated from issues of *knowledge* and *representation*. The success of implementing a technology depends on its use, and use depends on how the participants know and represent the reality they are dealing with. The central issue raised by linking technology to knowledge and representation is about rationality and objectivity. In that sense the travel of techno-scientific models in development and humanitarian interventions is inextricably linked to questions of rationality (what means do we have and what goals do we want to achieve?), identity (who are we?), and the objective representation of the reality out there (in what situation are we?). The hardest and most important of these these implications is the third one. The universalist presupposition of the one reality—prevalent in the epistemic community of development experts—implies that this one reality can be grasped, represented, and used a second time for verification. This seems to entail the possibility of a meta-code in which that reality can be represented without distortion. Following this assumption, the development discourse distinguishes between the one meta-code and many cultural codes. Given this understanding of the meta-code, the different cultural codes can only be 'wrong' since they design different realities while it is assumed that there is only one.

Critics usually intervene here: it is the universalist presupposition of the one reality which is flawed. However, the first problem with this critique is that it cannot be valid unless it takes the same universalist position. Saying that the different realities designed by different cultural codes have the same status, unavoidably requires a meta-code in which this very observation can be formulated. This is the well-known and extensively belabored paradox that will forever wait for its solution. The second problem with this critique is that it underestimates its own basic assumption about the historical, social and cultural situatedness of all knowledge. The enunciation of a meta-code unavoidably has its own situatedness: where people of different convictions and interests want to or have to act in accordance, they cannot do so without enunciating the possibility of a meta-code. In the words of Douglas and Wildavsky referring to risk assessment:

> Yet, act we must, not knowing what will happen to us along the path we choose to take. (Douglas and Wildavsky 1982, 4)

It is this "act we must" that is at the core of the epistemic community of development experts.

I suggest leaving aside the abstract debate about the possibility or impossibility of a meta-code founded in reality (assuming with Quine (1951) that all theories and the propositions derived from them are under-determined by empirical data). Instead, I propose to embark on an ethnographic description of social practices which need to *handle* the paradox without being able to resolve it. My main hypothesis is that the handling of the paradox is a form of *code-switching* between, on the one hand, acting and speaking in order to achieve something (e.g., making a water utility economically viable) and, on the other hand, reflecting about this acting and speaking in a different context with different rules, values, and reality assumptions, and with a different purpose (e.g., to impress an academic audience, or to find consolation among like-minded friends 'after the battle' in a private discourse). I should, perhaps, repeat that I do not consider this to be a cheap anthropological or sociological way around a fundamental philosophical question. I rather consider this to be an appropriate explanation of why meta-codes are unavoidable and why certain techno-scientific solutions become accepted as universal—at least for a while.

The general argument implied here is that good arguments do not necessarily travel better than poor arguments. This position follows a fundamental shift that is often attributed to David Bloor and his book *Knowledge and Social Imagery* (Bloor 1976). He convincingly argues that not only the perseverance of 'false beliefs' but also the perseverance and spread of 'true beliefs' requires sociological explanation because the truth of an idea does not seem to sufficiently explain its diffusion.[6] In organizational sociology DiMaggio and Powell (1983) have shown with an analogous argumentation that the spread of rational models of organizing normally follows fashions and results in what they call *mimetic isomorphism.* My argument on code-switching is also inspired by Niklas Luhmann's (1991) argument on *deparadoxification* meaning that the blind spot of observation and description cannot be eradicated but only exchanged with another blind spot—in my words: another code—that is less problematic for a purpose at hand.

To summarize the hypothesis: within the global organizational arena constructed around the ongoing concern of development there are numerous heterogeneous trading zones where the actors nevertheless have to and can agree on shared criteria of objectivity for their purpose at hand. Their emic assumption of universal objectivity with its corresponding meta-code is necessary for practical and

[6]Cf. also (Smith 1997).

diplomatic requirements of negotiations across epistemic differences. This implies that the emic assumption of universal objectivity does not need any other explanation—other than its pragmatic function in heterogeneous trading zones. This again means that a particular claim to universal objectivity is a provisionally valid assumption that is easily dropped outside the arena of negotiation and exchanged for another position that makes more sense in the arena one has moved to. This hypothesis also implies that the assumption of universal objectivity is misunderstood if reduced to a form of hegemony founded in power asymmetry. To the contrary, claims to universal objectivity can sometimes be used as a protective device against hegemonic encroachments like, for example, in all cases that can be understood as "speaking truth to power."

21.4 The Meta-Code in Heterogeneous Trading Zones

I can now come back to the approach by Douglas and Wildavsky and critically apply it to my case study. Development cooperation, as mentioned in the introduction, is mainly carried out in projects. For my argument, the most important characteristic of development projects is the frequent occurrence of epistemic heterogeneity within the arenas of negotiation opened up by projects. The degree of heterogeneity and the chances of its occurrence increase when stake holders from outside the demarcated project domain and from outside the epistemic community of development experts are involved in negotiations. A negotiation technique called Goal-Oriented Project Planning (GOPP) has been developed for this field in an explicit recognition of the problem of heterogeneity.[7] Four pictures from my case study and a four-field-scheme taken from Douglas and Wildavsky will help to examine the logic of this technique.

The first picture (Figure 21.1) shows a group of experts sitting in a hotel hall in Dar Es Salaam (Tanzania) in 1994 exploring over a beer what could be done in order to improve the water and sanitation related health situation in some Tanzanian towns. They do not yet know where they stand, who the stakeholders are, what the problem really is, and they have no clue what intervention they could envisage as a joint enterprise. They are fully aware, though, of the expectations and restrictions set by their principals for their activities. Additionally, they know these restrictive parameters to be in accordance with globally circulating notions of state devolution, deregulation, and privatization. Hence they know that they cannot come up with some etatist solution to the water related health situation in Tanzanian towns; but then *privatization* is still a very vague goal that allows for nearly endless variations.

The second picture (Figure 21.2), taken in 1995, documents the examination of one aspect of the water related health situation that was identified as a key factor, namely the administration of the water works and particularly of the customer files, in a town called Arusha. The project experts have to analyze the customer

[7] Cf. (Helming and Göbel 1997).

Figure 21.1: A group of experts in a hotel in Dar Es Salaam exploring ways of improving the water and sanitation related health situation in some Tanzanian towns.

files (on the shelves at the back of the office) and check their reliability since this has vast implications for the financial situation, and in turn determines the level of maintenance—at least under the assumption that the water works should be economically viable, independent units.

The third picture (Figure 21.3), taken in 1996, shows part of a group of administrators, engineers, managers, and financial experts GOPPing to define the relevant goals and means for the same development project, this time in a town called Moshi. In the background one can see the notes of the participants pasted on the wall. The actors shown in this picture already know their facts, yet they still have no consensus about where exactly they want to go with this project and, in particular, do not know exactly who has to do what in order to get there.

The fourth picture (Figure 21.4), taken in 1997, shows two hydro-engineers, a consultant and an anthropologist in an office of the waterworks of Moshi. A notebook computer is at the centre, with Microsoft Excel on the screen representing the plan of action for the project. They are clear about all the facts they need to know, about all the means and inputs they have at hand, and they have a more or less unambiguous aim: to bring the waterworks to economic viability. They are, in other words, calculating and optimizing the procedures.

The four pictures document a process that took place between 1994 and 1997 and they show a particular development. The same development can be visualized by the four-field-scheme taken from (Douglas and Wildavsky 1982, 5) that is built on two axes: the horizontal axis represents *knowledge* (about the problems to be tackled by the project) while the vertical axis represents *consensus* (about the

Figure 21.2: Examination of the water related health situation in Arusha.

means and the goals of the project). With the additional distinctions between certain or uncertain knowledge, and complete or contested consensus there are four fields:

		Knowledge	
		Certain	Uncertain
Consensus	Complete	Field 4 Problem: Technical Solution: Calculation	Field 2 Problem: Information Solution: Research
	Contested	Field 3 Problem: Disagreement Solution: Negotiation	Field 1 Problem: Knowledge Solution: move to Field 2

The four pictures can now easily be attributed to the four fields according to their sequential numbers from 1 to 4. The table and the pictures, however, do not depict a necessary order of operations; it is an endless iteration process in which any field can be used as the starting point. As soon as a problem emerges, a search process

Figure 21.3: A group of experts defining the goals and means for a project in Moshi.

is initiated, which can ideally be separated into these four steps that are taken repeatedly. Negotiations in fact rarely begin in Field 1; some negotiations might be drawn back into Field 1, though. And in reality iteration processes are not neatly divided in four steps; normally all four steps are negotiated more or less at the same time. This, however, does not reduce the value of this table as heuristic device.

In Field 1 (see Figure 21.1) it is uncertain in what kind of situation one actually is in and in which direction one could or should go within the broad horizon of state devolution, deregulation, and privatization. It is undecided who the affected parties are, who is legitimized to speak for whom, how different the affected parties see the situation, and what their interests really are. In fact, parties and their interest might not be something simply given in advance, but might be something resulting out of these kind of negotiations. It is even uncertain how to acquire the knowledge necessary for clarifying this vague situation. If the negotiations in Field 1 are to have any chance at all, the actors must move together to Field 2. In Douglas and Wildavsky's terms, this means that the actors simply need to improve and substantiate their knowledge about these elementary questions. In my terms, though, the consensus necessary for the move into Field 2 is, in the first

Figure 21.4: Two hydro-engineers, a consultant and an anthropologist in an office of the waterworks of Moshi.

place, achieved primarily by bracketing all those dimensions that would possibly challenge a common definition of what it is all about, that is, by agreeing on a provisional definition of a supposedly common ground. Since it would be disruptive to investigate at this stage how far the agreement is really based on true convictions, the process basically starts with a form of bluffing—and, as I argue, could hardly start otherwise. Already here, in this provisional agreement, power relations play a decisive role. Yet, even more decisive seems to be the power of certain models of rationality that are believed to stand behind the successful handling of similar situations elsewhere. The chosen model—in this case a particular form of privatization of public utilities—is attributed universal validity simply by being chosen again and again all over the globe and thus becomes global knowledge as a result of being chosen. It is in this way that the model becomes an actant in a field of distributed agency.

In Field 2, according to Douglas and Wildavsky, a consensus must be reached on aperspectival, objective facts, which may lead to making the right decisions later on in Field 3. This, as I like to add, is again mainly facilitated by choosing procedures and instruments that carry the weight of being worldwide the best available for the purpose at hand. One cannot get facts about a situation without a prior choice of appropriate procedures, and these procedures again are traveling technologies. In Figure 21.2 one can foresee what inevitably will happen: the information from the files on the shelf will be transferred into a software package. In fact, the process already started, and the big white sheets on the desk of the accountant are computer printouts from one of those printers using endless paper. Like here, models and artifacts are utilized as *boundary objects* that are able to link heterogeneous fields because they are functional in several of them independently of the diverging basic assumptions in these fields (Star and Griesemer 1989; Fujimura 1992). After having achieved this, the actors must move on to Field 3 if they intend to realize a concrete cooperation. This is because the improved scientific knowledge of Field 2 does not imply evaluative and prescriptive propositions that would indicate what to do. In Field 3, therefore, the parties to the negotiation need to come to an agreement as to their preferential goals, and how these are best achieved based on the acquired knowledge. Once a prescriptive agreement has been reached through consensus—in this case via a GOPP procedure as shown in Fig. 21.3—the only remaining problem is to calculate the technical aspects of the cooperation in Field 4, as shown in Figure 21.4.

The four-field scheme, as mentioned above, is built on two axes: differentiation of knowledge on the horizontal axis and consensus on the vertical one. This distinction corresponds to the difference between facts and values, or between what is true and what is good. In more abstract terms, the key difference here is between a denotative language game and an evaluative or a prescriptive language game (Lyotard 2005). Yet the distinction between the two is a heuristic one, and the four-field scheme actually visualizes nicely how each field—or each step—of the iteration process is actually an intersection between knowledge (fact) and consensus (value). The work in Field 2 and Field 4 are no pure *technical* activities taking place outside of normative considerations. They are (like all technical activities and enabling devices) interwoven with values and interpretations that depend on a frame of reference including epistemic, normative, material and also aesthetic dimensions. The use of traveling technologies—with their black-boxed cultural bias—is an important instance illustrating this point. The same is true the other way around: the disagreements on goals and means in Fields 1 and 3 cannot be reduced to evaluative and prescriptive factors since these fundamentally depend on techno-scientific positions.

The four-field scheme also helps to see how and why the parties to a negotiation under conditions of heterogeneity need to pragmatically restrict themselves to a limited number of questions and to agree on standardized procedures recognized elsewhere. At the same time they are aware of operating within an endless iteration process that they can bring to a stop only by avoiding fundamental questions drawing them back to Field 1. A persistent revisiting of Field 1 would result in an infinite loop in which the actors remain unable—at least for a time—to come to a denotative solution in Field 2, and an evaluative solution in Field 3. Without the determinations in Fields 2 and 3, arriving at Field 4 would never occur, and hence the intended cooperation would not materialize.

During the iteration process all information that is not absolutely necessary has to be excluded heedfully or else the process is again and again set back to square one. In addition to this limitation, the information that forms the basis of the negotiations is presented in standardized forms that have been agreed upon in advance and are valid outside the immediate context. Ultimate justifications for the truth of statements (*Letztbegründungen*) are replaced by *formalized procedures of evidence*.[8] This procedure shifts attention from the question of correspondence between individual statements to outer reality, to the question of connectivity of the statements to one another (*Anschlussfähigkeit*). The problem of *external reference* is pushed into the background in favor of the *coherence criterion*[9] and hence the question of *transversal or circulating reference* (Latour 1995). In other words, the *procedure* receives priority over the *matter* being discussed (Luhmann 1993). This is the only possible way to achieve concrete co-operation under conditions of heterogeneity.

While this is the case, and for the duration of the negotiations, the actors need to avoid making the priority of the transversal or circulating reference over the external reference an open issue. The negotiation can only proceed under the as-if-assumption that the meta-code was valid because it was *naturally* anchored in external reality and *therefore* transcended all particular frames of reference. Otherwise, one would have to conclude that the debated matters can be seen differently from each point of view. Any decision taken under this relativistic assumption would look arbitrary and illegitimate and in some situations absolutely intolerable. Court procedures are a particularly obvious example of this discursive rule. One argues in court about the truth, but the rules by which one argues are agreed upon before and are strictly codified. If the indictment cannot be formulated in these codified rules and legal terms, the prosecution will draw attention away from the actual facts—often in stark violation of common sense—to other facts which can be translated into the legal procedure. The same pattern is at work when the immediate veracity of evidence given at court (like the result of a DNA analysis) is not as important as the formal criteria of its validity as evidence (e.g., when the specimen for the DNA analysis was taken without consent from the person concerned).

In the perspective chosen here, the enunciation of a single and attainable reality with its respective meta-code of representation is thus a political and juristic necessity. A standardized set of rules—the elementary rule being the key differentiation between denotative and evaluative language games—is necessary to remove from negotiation processes any sense of arbitrariness. It is here that technology and the technical game come in as salvation. Even if it is a very doubtful salvation with serious iatrogenic effects—that is unintended negative consequences—there is no better salvation in sight.

If we cannot get rid of them, it appears reasonable to keep the enunciation of objective, globalized knowledge and technical games to what they initially were: provisional agreements used to enable a specific cooperation under conditions of heterogeneity. The uncertainty that results from such a paradox assumption is

[8] Cf. (Porter 1992, 1995); this point was already made by Heidegger in 1938 (2003, 84).
[9] Cf. (Davidson 1986).

insurmountable and simply has to be endured. The epistemic community of development experts has developed a deep understanding of the impossibility to go beyond code-switching when it is about co-operation across epistemic differences. This practical knowledge can be improved by making it explicit and turning it into a strong reflexive competence to shift back and forth between the position of a true believer in the meta-code enunciated during the negotiations and the position of a true skeptic of the same thing outside the negotiations.

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Chapter 22
The (Ir)Relevance of Local Knowledge: Circuits of Medicine and Biopower in the Neoliberal Era

Hansjörg Dilger

22.1 Introduction

In the volume *Knowledge, Power, and Practice: The Anthropology of Medicine and Everyday Life* Shirley Lindenbaum and Margaret Lock (1993) have argued that the production and dissemination of biomedicine in societies worldwide has become inseparably intertwined with the social hierarchies, cultural mechanisms and moral, ethical and legal priorities prevailing in local and global power relations. In the context of modernization and globalization, the authors argue, the expansion of biomedicine cannot be thought of as being seperate from the way in which a more encompassing worldview and way of being is being enforced, produced and sustained. This is often achieved by marginalizing and rendering irrelevant other competing systems of (medical as well as non-medical) knowledge, practice and seeing the world.[1]

With regard to colonial Africa, Jean Comaroff (1993) has shown that the cultural legitimacy of biomedical knowledge was established not so much by emphasizing its scientific effectiveness and/or biomedicine's pro-spective benefits for the colonized populations' health, but rather by stressing biomedicine's alleged moral superiority: Colonial bureaucrats and medical doctors propagated the idea that the acceptance of biomedically defined "healthy" lifestyles had become the necessary precondition for the social, moral and economic advancement of the colonized societies and for establishing a civilized and stable social order in the context of the colonial setup.[2]

Other chapters in *Knowledge, Power, and Practice* argue that the introduction and implementation of biomedical knowledge in various parts of the world has implied—and continues to imply—intense struggles over (health-related) meaning and practice on multiple levels of society, and the concurrent labeling and stereotyping of alternative forms of healing and religious, social and ritual practice as "traditional," "backward" and "superstitious." This latter view is often promoted not only by governmental and nongovernmental bodies and their representatives, but also by those parts of populations which identify themselves with "more ed-

[1]This article contains large sections of a forthcoming chapter (Dilger 2012).
[2]See (Comaroff 1993); see also (Vaughan 1991).

ucated" and "modern" worldviews. As Comaroff (1981) has argued, discourses on illness, healing and ritual are often more about the micropolitics of identity production than about specific persons and groups *being* "traditional" and/ or "anti-modern."[3]

The intimate relationship that exists between the production and circulation of biomedical knowledge and practice, on the one hand, and the establishment and perpetuation of globally and locally enforced worldviews, identities and power relations, on the other, has become nowhere more explicit than in the field of international development. The power dynamics that have been put in place by the globalized development framework over the last decades can be read in very different ways. One first version would be: Over the last twenty to thirty years, the economies and welfare systems of "Third World" countries have been reconfigured most drastically by reform programs imposed by the World Bank and the International Monetary Fund (IMF). From the late 1970s and early 1980s onwards such programs offered limited opportunities for national and local governing bodies and populations to negotiate well-being, knowledge and practices that contradicted the priorities and "urgency measures" dictated by international donors and development experts.[4]

However, while globalization and neoliberal reform processes have admittedly had a long-lasting effect on the political, social and economic configurations of many countries in the developing world,[5] it would be an oversimplification to describe these processes *exclusively* with regard to the one-sided power relations that have shaped the positions of the "poor" and "rich," "developed" and "underdeveloped" in a hierarchically structured world order. Thus, a second version of the history of international development would emphasize the fact that from the mid-1980s onwards international donors and development experts aimed not only at integrating local knowledge and expertise into the planning, organization and implementation of local development programs and projects. Development experts and project planners have also argued for actively decreasing the power hierarchies prevailing between the various "partners" involved in specific development projects in order to contribute "more effectively" to the material and social advancement of societies and populations in the developing world (Green 2000). According to this latter view, "participatory approaches" in development imply the planning and implementation of projects and programs as the result of a process of mutual learning and interaction that is targeted first and foremost at the "empowerment" of local populations. As Maia Green puts it:

> 'Development' is not [then] simply a process of directed change leading to certain kinds of economic and social transformation, but depends on the accomplishment of a series of corresponding moral transforma-

[3]See also (Pigg 2002).

[4]On the technical and naturalizing language used by World Bank experts and economists in the context of structural adjustment, see (Ferguson 2006, 71).

[5]Cf. (Escobar 1995; Ferguson 2007).

> tions in the consciousness of people participating, as change agents and changed, in the development process. Consequently, the proper task of development organizations and their personnel is to facilitate the necessary transformations in consciousness which can *empower* the poor as social actors to embark on locally managed change. (Green 2000)

While this is not the immediate focus of my chapter, it should be mentioned here that the ideals of "partnership" and "empowerment" are seldom translated into actual practice. Thus, a third way of interpreting the international development framework would highlight the fact that attempts at the realization of the partnership and empowerment paradigm have often led to paradoxical relations between actors in the field who, while often being critical or even cynical about the contradictions contained in development, ultimately affirm and reproduce the overall system (Green 2000; Rottenburg 2009; Marsland 2006).

This chapter builds on all three approaches to globalization and development and looks at the way globally defined ideas about development, empowerment and knowledge production have been realized in the context of globalization processes of the last fifteen to twenty years in Tanzania, where development has become inseparably intertwined with neoliberal reform processes and the launching of structural adjustment programs in the country from the mid-1980s onwards. Focusing on the realm of HIV/AIDS programming and intervention, I will show that the multiple projects that have been established in the context of HIV-prevention, care and treatment programs—and the various types of knowledge these projects and programs produce and rely on—have become embedded in the global economy of aid, which has shaped the economic, social and cultural realities in wide parts of sub-Saharan Africa over the last decades. In particular, these programs and projects have focused on the promotion of "technologies of the self" and the production of subjectivities that rely strongly on the rationality and self-reflexivity of "empowered" individuals in forging appropriate and "healthy" ways of dealing with the disease.

The second part of the chapter will focus on some of the *responses* that rural and urban populations in Tanzania have articulated in relation to the HIV/AIDS epidemic and that have become intimately intertwined with people's concerns about familial, social and economic developments in the context of modernity and globalization, and the moral and reproductive order at large. I argue that the implementation of "biopower" in rural and urban Tanzania, and thus, the production and circulation of biomedical knowledge in the neoliberal era, have to be understood as a fragmentary and contradictory process, which has become closely entangled with the way in which the global development industry is (re)creating zones and spaces of social service provision and health-related interventions in the East African region in the wake of neoliberal reform processes and emergent forms of globalizing humanitarianism.[6] While biomedicine and processes of medicaliza-

[6] Cf. (Ferguson 2006).

tion have played an important role in shaping individual and collective knowledge and behavior in relation to the disease in many parts of the continent, people are often *simultaneously* relying on alternative forms of knowledge and action in defining socially and morally appropriate ways of dealing with illness and death in the context of a transforming socio-moral and political order.

In the formulation of my argument, I rely strongly on my fieldwork in rural and urban Tanzania, which from 1995 onwards has explored different aspects of the interconnection between HIV/AIDS, knowledge production and social relationships in the context of globalization and modernity, including issues surrounding sexuality and gender relations, relationships of care and support, the moral management of AIDS-related illnesses and deaths, and recently the introduction of antiretroviral treatment, which has shaped health policy in Tanzania since the end of 2004.[7]

22.2 Governing Health in the Era of Structural Adjustment and HIV/AIDS

At the end of the 1970s, most countries in the Eastern and Southern African region stood on the verge of economic and political collapse. Governments were confronted not only with growing external debts and exploding costs in heavily subsidized economies and over-funded welfare systems, they were also struggling with the consequences of the international oil crisis and the global economic depression. All these factors combined drove many African governments to turn to the World Bank and the International Monetary Fund for assistance. The loans which were granted to African states by the World Bank and the IMF were intended primarily for use in stabilizing economies and paying-off national debts. However, they were also made contingent upon the implementation of a series of structural reforms in the respective countries which entailed, amongst others, currency devaluation, the reduction of trade barriers and the privatization of state-owned enterprises. Structural adjustment policies (SAPs) implied furthermore a steep reduction in governmental expenditure for healthcare, education and housing programs, including a drastic reduction of salary expenses for public sector employees.

The effects of structural adjustment on Tanzania's healthcare sector were manifold. The former socialist country, which had banned private medical practice in 1977 in order to eliminate "profit thinking in the face of human suffering" (Iliffe 1998, 209) reopened its healthcare system for private practitioners and health institutions in 1992 (ibid., 217). In 1999, there were already more than 500 private clinics and hospitals in Dar es Salaam alone (Boller et al. 2003, 117). In the year 2000 the government counted more than 1,270 private or religious dispensaries and 76 nongovernmental hospitals throughout the country.[8] Cost-sharing programs,

[7] Cf. (Dilger 2003, 2005, 2008).
[8] See http://www.tanzania.go.tz/health.html.

which were initially opposed by the former President Nyerere and his "socialist supporters"[9] placed heavy burdens on patients and their families who, in addition to hospital and clinic charges, had to cover costs for transport, food, (admission) bribes, drugs and other medical supplies. In 2004, a report by the *Women's Dignity Project* stated that "health care charges [in the country] have placed an impossible financial burden on the poorest households"; many fail to access primary care when they need it most and many more fail to obtain the necessary referral for more skilled care (Mamdani and Bangser 2004, 151). Finally, the introduction of SAPs led to drastic cuts in state expenditures for the healthcare sector, and to an ever-growing reliance of Tanzania's healthcare system on international and private funding to make up for the growing deficit: In 1990/1991, the national budget allocation for healthcare in Tanzania had fallen to 5% from 9.4% in the 1970s (Harrington 1998, 149). In 2004, 49.9% of capital expenditure for the healthcare sector came from external sources; private expenditure on health, the largest share of which were out-of-pocket expenditures by patients and households (75.0%), amounted to 34.2%.[10]

The growing fragmentation and privatization of Tanzania's public healthcare system—and the concurring influx of external funding into the country's healthcare system—have become especially pervasive in the field of HIV/AIDS. Since the UN Declaration of Commitment on HIV/AIDS in 2001—and the subsequent launching of the Global Fund for the Fight Against AIDS, Tuberculosis and Malaria (2001) as well as the US Presidential Emergency Plan for AIDS Relief (PEPFAR) (2003)—international funding for the epidemic amounted in 2005 to more than eight billion US$ on the global level. In Tanzania, financial resources for the fight against the epidemic increased steeply after the country was selected as one of the PEPFAR's fifteen focus countries[11]: Under the Emergency Plan, Tanzania received more than 70.7 million US$ in Fiscal Year (FY) 2004, nearly 108.8 million US$ in FY 2005, and approximately 130 million US$ in FY 2006 to support comprehensive HIV/AIDS prevention, treatment and care programs. In the years 2004/05 donor funding comprised 94.6% of the total public expenditure for HIV/AIDS and amounted to 377.8 billion Tanzanian shillings (ca. 219.6 million US$) during the same period (TACAIDS 2008).

As in other countries in the sub-Saharan African region, international funding for HIV/AIDS in Tanzania is channeled partly through governmental institutions (in the case of treatment), and partly through the programs of NGOs, which have the reputation of providing transparent and accountable entry points for community-based development. In 2003, one NGO consultant in Dar es Salaam related that HIV/AIDS had become a "hot topic" in the country. Organizations that had not been involved in the topic so far were starting to engage in the fight

[9] Cf. (Iliffe 1998, 208).
[10] See the World Health Statistics for 2007 at http://apps.who.int/ghodata/?vid=20700.
[11] Among PEPFAR's fifteen focus countries, which represent collectively approximately 50% of HIV infections worldwide, are five Eastern African countries: Ethiopia, Kenya, Rwanda, Tanzania and Uganda.

against HIV/AIDS in order to attract additional funding; new NGOs were founded on a daily basis, existing sometimes only as "briefcase NGOs." Finally there was growing competition between individual organizations aiming to develop new and innovative strategies of prevention, care and treatment in their constant struggles to attract donor money.

While the field of HIV/AIDS work has become increasingly complex and also short-lived, with many AIDS organizations attracting one or two-year funding commitments from a variety of mostly European and North American donors, HIV/AIDS-related programs have gradually subscribed to a focus on human rights and empowerment. This new type of intervention has placed the self-reflexive individual at the centre stage of HIV/AIDS-related policies and has granted the empowered actor with the capacity to deal responsibly and circumspectly with the risks associated with HIV infection and AIDS illness. To phrase it in the words of Michel Foucault the empowerment approach expects people to successfully apply

> […] technologies of the self, which permit individuals to effect by their own means or with the help of others a certain number of operations on their own bodies and souls, thoughts, conduct and way of being, so as to transform themselves in order to attain a certain state of happiness, purity, wisdom, perfection, or immortality. (Foucault 1988, 18)

To make sure, such an approach is not entirely new in the history of healthcare and healing in the wider Eastern and Southern African region, especially with regard to the field of mission medicine which was concerned explicitly with the formation of subjects. However, while subject formation has not been the focus of the wider, predominantly repressive power regime of the colonial state which was only marginally interested in the transformation of its citizens' life worlds and individual and collective consciousness (Vaughan 1991), the promotion of self-governing individuals in the post-colonial setting was constrained mostly to the level of health experts (Langwick 2012) and did not rely on media and market forces to the extent it did in more recent decades. Furthermore, the more recent empowerment approaches are also different from earlier, information-based approaches in HIV prevention that were directed at an undifferentiated collectivity and often tried to make people fearful of possible infection with the deadly virus.

This "approach of deterrence," as I would like to call it, is exemplified by the two figures below: Figure 22.1 represents a poster from Ghana from 1989 and displays a skeleton that is surrounded by messages concerning possible ways of HIV infection, thus scaring people about the deadly consequences of HIV. The same approach is used in a mural painting in Dar es Salaam (Figure 22.2) which simply states "AIDS is Death" (*Ukimwi ni kifo*) and, on the left, "Fear AIDS" (*Ogopa ukimwi*). Today, such generalized messages of deterrence have given way to empowering and participatory approaches, which have also gained ground in other areas of development work. In contrast with the earlier information-based approaches (including the "ABC approach" which relies on the tripartite message

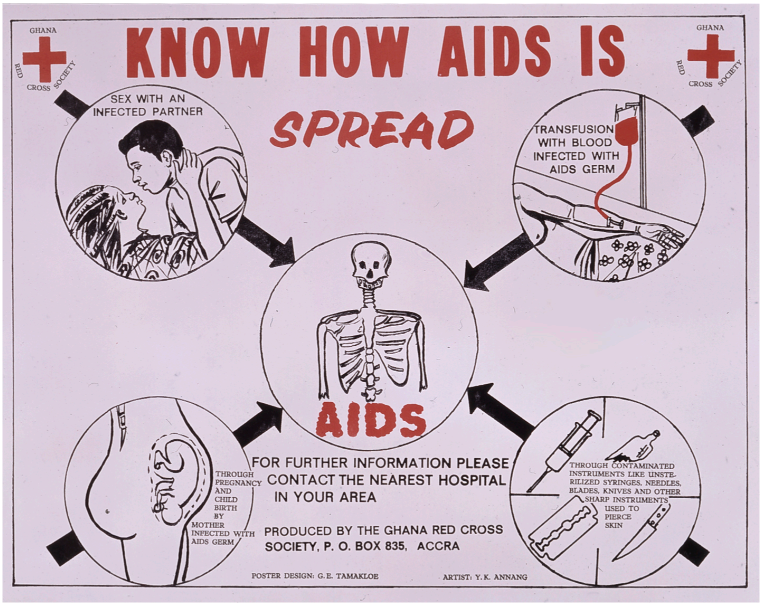

Figure 22.1: AIDS Poster, Ghana Red Cross Society 1989. (Source: Deutsches Hygiene Museum, Dresden)

Figure 22.2: Mural painting in Tanzania, 1999. (Photo: Dilger)

"**A**bstain, **B**e Faithful, or Use **C**ondoms"[12]) the empowerment approach no longer simply tells people what to do or what not to do, i.e., how HIV is transmitted and what the consequences of risky behavior are in terms of infection and death. While such knowledge is *implicitly* contained in the "new" type of interventions, current prevention efforts are creating differentiated positions, which *may* be assumed in relation to HIV/AIDS, based on differences in age, gender, living environment, and also with regard to the professional and educational background of the respective target groups.

22.3 Technologies of the Self in "New" Approaches to Prevention, Care and Treatment

In Tanzania, technologies of the self in relation to HIV/AIDS policies are to be found most explicitly in prevention programs that focus on the growing urban middle class and that promote a discourse on "romantic" and "true" love among young people according to which partners talk openly about sexuality and birth control, as well as about protection from sexually transmitted diseases. This group of young people is sometimes called the "condom generation," and in a broader sense it can indeed be understood as a reaction to the HIV/AIDS epidemic. The young men and women that are addressed by these interventions have become the target of a growing market of internationally-funded campaigns, which use different types of media interventions including talk shows, glossy magazines, counseling sections in newspapers, call-in radio shows etc., and which promote a view of sexuality that has become individualized and detached from family relations.

All these interventions targeted at young people are responding to the questions individual girls and boys may have about sexuality and HIV/AIDS. They offer advice with regard to specific life situations, which represent a risk in terms of HIV infection and, most importantly, they talk about the pleasures of sexuality. Thus, whereas earlier campaigns assumed that people know how to have sex and how to manage sexual relationships, this knowledge is no longer taken for granted and has to be negotiated.[13] "True love," as discussed and promoted by advice columns and picture stories run by fashionable lifestyle magazines, is based not solely on sexual attraction or satisfaction, but rather on values like friendship, loyalty, trust, respect and finally tenderness. The general message of such campaigns is that condoms are a sign of trust and mutual respect, not of mistrust or a way of blaming one's partner for not being knowledgeable about sexuality and HIV.[14] That this implies in turn an acknowledgement of responsibility to one's self for one's *own* health, and that safe sex can therefore be "cool" (Posel 2005, 133) is expressed in the statement by twenty-two-year-old Shaban, the male character in

[12] For a critical analysis of the ABC approach, see (Heald 2002).
[13] Cf. (Parikh 2005).
[14] Cf. (Dilger 2003).

a picture story run by *Femina*, a health journal for young people in Tanzania. He says:

> If you want to be a winner in the game of love and pleasure, you have to go for condoms. (Femina 2000, 25)

On another level, technologies of the self have come to play a crucial role in the politics of "Living Positively" that have shaped HIV-positive identities all over sub-Saharan Africa during the last ten to fifteen years. Originating in Uganda in the early 1990s,[15] this model provides a way for people with HIV/AIDS "to take care of their mind and body" and to enter into a "healthy relationship" with the life-threatening disease by a number of regulative practices and devices. These practices include the adherence to dietary requirements, regular medical checkups, the consistent treatment of opportunistic infections and finally the maintenance of social activities and regular exchange with others on dilemmas and problems associated with an HIV-infection. In Tanzania, this latter aspect has materialized in the form of numerous NGO support groups for people with HIV/AIDS, which provide a forum to discuss, negotiate and form opinions about various issues related to the illness. Topics discussed in the support group meetings in Dar es Salaam in 1999/2000, which took place on a regular basis and where people met three to four times per month, included disclosure and stigma, the challenge of balanced nutrition, "safe sexuality" in short- and long-term relationships, the lack of material support in times of illness, the writing of a will and the gains and disadvantages of traditional medicine.

Beyond the pragmatic advice and the material aid provided by NGOs, the discussions in the support groups also fulfil a therapeutic function: It is through these extended conversations that people with HIV/AIDS (ideally) learn to accept their illness and to acquire a future-oriented and self-conscious approach to dealing with HIV. The information and advice given with regard to problems in partnerships, families or at the workplace is specific as well as generic and is becoming an essential part of the process of building a "positive identity," despite experiences of grief, stigmatisation or despair about one's material life circumstances (see Figure 22.3). Only few support group members I interviewed in Dar es Salaam were capable of initiating this healing process on their own. It was only through the repeated counselling and identification with the suffering of others that people adopted a self-image of being HIV-positive and translated this self-image into the context of marital and non-marital relationships, kinship networks and the wider community.

A final issue that has shaped the politics of HIV-positive identities in more recent years is the introduction of antiretroviral medications (ARV). ARVs have become available in Tanzania since the end of 2004. In collaboration with PEPFAR and the *Global Fund*, newly created treatment centres have been established

[15] Cf. (Dilger 2001).

Figure 22.3: The aspect of individual and collective counseling is addressed in images and stories of hope as presented in the booklet "Living Positively" (*Kuishi kwa Tumaini*: Living with Hope). The main character of the picture story displayed here is confronted with an HIV-positive diagnosis and—after going through a period of internal struggle and despair—has accepted his HIV-positive status. He says: "After I have talked to the counselor, I feel good. I know that I can talk to these organizations. They offer services whenever I am in need of advice or when I need a person to talk to." The booklet "Living Positively with HIV" represents a good example of the way in which public health responses have become embedded in transnational channels of funding and knowledge production: The booklet has been adopted from the Soul City Institute for Health and Development Communication in South Africa and translated into Kiswahili and "culturally adapted to the Tanzanian setting" by the Health Information Project.
(*Femina*, HIP, Tanzania)

all over the country. A number of booklets and handouts have been produced that stress the necessity of taking ARVs according to a fixed schedule and being aware of the importance of sticking to these drugs forever: "These expensive medicines," reads one booklet which was adopted from the *Soul City* project in South Africa, "have to be taken every day, every month, your whole life." Multicoloured pamphlets call on people to observe their bodies carefully and to report unusual changes, symptoms and side effects to their physicians. ARVs are prescribed on a monthly basis and the dates of the last health clinic visit as well as the recommended return for check-ups are marked on a blue card that is used specifically for the prescription of ARVs and that allows people to visit other treatment centers around the country while traveling. Finally, the health planners see it as crucial for the success of ARV treatment that families and friends establish an open dialogue about these drugs in order to create a supportive environment for consistent and continuous drug regimens: "It is good to be with someone you trust," reads one leaflet, "be it a relative or a friend, he will help you to remind you to take your medicine [as prescribed]." Thus, while people have been urged "to live positively with HIV" for more than a decade now, today they are required to "make a lifelong contract" with medications that have transformed the life-threatening disease into a chronic condition.

22.4 Beyond NGOs and "the Clinic": Local Moral Worlds and the Limitations of Biopower in Tanzania

Looking at the numerous interventions that have been established in the field of HIV/ AIDS over the last couple of years, one may wonder which particular "truths" about the disease (in the sense of Paula Treichler (1999)) or, which type of "moral regimes" (in the Foucauldian sense), are being promoted by health programs in Tanzania that have evolved in the context of a market-driven, mostly nongovernmental and transnationalized response to the epidemic. In this section I want to argue that the empowerment approach—and the social, cultural and economic practices that are associated with it—are confined to specific settings; settings which can be described as "islands of biopower" that are sustained by the international AIDS industry which has based its activities increasingly on notions of human rights and self-responsibility and in recent years has aimed at the involvement of "affected communities" in its manifold activities.[16]

In medical anthropology, practices, ideals and technologies of the self, originating in the context of illness, health and well-being, in recent years have become closely related to discussions of biological citizenship; a form of citizenship that refers to the biological dimension of human life and "embodies a demand for particular protections, for the enactment or cessation of particular policies and actions [and for] access to special resources" (Rose and Novas 2004, 441). In the context of HIV/AIDS, Vinh-Kim Nguyen (2005, 126) has subsumed the various practices,

[16] Cf. (Nguyen 2005).

values and ideas that have emerged in the context of a globalized health response under the concept of therapeutic citizenship: a transnationalized form of biological citizenship, which makes claims on the global economic and social order based on a “shared therapeutic predicament.” According to Nguyen (2005, 125f.), the social and cultural practices, which have evolved in this context over the last ten to fifteen years, have been organised around a complex set of confessional technologies and processes of self-fashioning. These are closely interwoven with internationally acclaimed forms of HIV/AIDS activism and essentially draw their legitimacy from the economic, political and biological inequalities existing in a globalizing world.

The practices and technologies of the self, which are evolving under these circumstances, can now be described with the concept of “biopower” which according to Foucault (1977) involves the exercise of power on a double, mutually intertwined level. On the individual level, the exercise of biopower presupposes a specific type of relationship with one’s body, as well as a specific type of subjectivity. Thus, whereas the exercise of state power is aiming at the regulation and control of the population as a whole, the exercise of individual power aims at the disciplining of one’s own body, the regulation of desire and the refashioning of the responsible sexual self. In this context, the care of one’s own health and body are intimately intertwined in that both are protected, cultivated and isolated from anything that is considered undesirable and dangerous. This creation of the “healthy self” through the application of technologies of truth and knowledge seems not dissimilar to the way in which the interventions of the mostly internationally funded AIDS-NGOs in Southern and Eastern Africa have come to present sexuality. According to Deborah Posel (2005, 134) for AIDS NGOs—and certainly to some of their clients and target groups—sexuality has become a “site of rational, individual choice and agency, an opportunity for empowerment and ‘healthy positive living’.”

If we look now at the rural areas of Tanzania—and also beyond the context of NGOs and clinical settings in urban centers—we find that the ways people deal with HIV/AIDS are based as much on knowledge, discursive processes and technologies of the self that are derived from governmental and nongovernmental AIDS campaigns as they are embedded in the wider political economies of healthcare in Tanzania, and the social and moral priorities formulated by communities and families in relation to the disease. I want to illustrate this aspect briefly with regard to the ways families and communities in the rural Mara Region in Northwestern Tanzania—as well as in a Pentecostal congregation in Dar es Salaam—have come to deal with HIV/AIDS-related illnesses and deaths.[17] While I focus on the ways

[17]While my critique of concepts like “biological” or “therapeutic citizenship” in this section focuses mostly on settings and relationships situated *outside* of NGOs and biomedical institutions, the validity of these concepts has also to be questioned for the context of NGOs itself as well as for the biomedical sector in general. Thus, as Whyte (2009) and Whyte et al. (2010) have argued, the rollout of antiretroviral medications raises challenging questions for anthropological debates on ethics, subject formation and understandings of biological and/or therapeutic citizenship. These questions may become even more pertinent with the current cutbacks in global funding

in which people's responses to HIV/AIDS have been shaped in specific settings of Tanzania beyond the NGO context, it should become clear that the processes and practices I describe here are not situated *outside* the globalized AIDS response and health sector in Tanzania. They have become inseparably intertwined with the processes described above in that they evolve *in relation to* the needs and challenges experienced in the wake of structural adjustment, privatization and the implication of Tanzania's health system in transnationalized forms of governance. Furthermore, it has to be kept in mind that many of the HIV-positive women and men I encountered in Tanzania belong not only to one neatly bounded social entity or group, but identified themselves (sometimes only temporarily so) as NGO clients and/or church members along with their emphasis on being part of one or more kinship networks.

22.4.1 Kinship, Care and Relatedness in Rural Mara

At the time of my research in the rural Mara Region in 1999/2000 governmental and nongovernmental care programs were established only in rudimentary ways.[18] The expensive care and treatment provided by local private hospitals was affordable to only a few rural families, who lived primarily from agriculture and petty trade, in part from fishing and from the support of family members who were living and working in the cities. Relationships of care and support in this context were shifted out of necessity to the families with members with HIV/AIDS and were embedded, amongst others, in family conflicts, the beginnings of which often existed long before the outbreak of illness. Especially with regard to sick relatives from cities like Dar es Salaam, Mwanza or Arusha, family tensions had an effect on situations of care provision as sick relatives who had been living in the city often returned unwillingly to their home villages under pressure from their (urban) relatives. On the other hand, the return of these relatives, who in some cases had paid little attention to the well-being of their rural families during preceding years, presented a significant economic, social and emotional strain for their rural family members (Dilger 2005, 2006, 2008).

In addition to the internal family conflicts and significant social and economic difficulties the care of family members sick with AIDS in a rural setting implied,

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for antiretroviral treatment and the impact this may have on the accessibility of local and national treatment programs (Medecins Sans Frontières 2010). Furthermore, the confines of this article do not allow me to elaborate on the manifold social and cultural processes influencing not only the domains of care and illness experience, but also sexuality in rural Tanzania. Thus, while a discourse on "true love" is taking place even in rural areas, other aspects such as inequality between the sexes, the significance of gifts and money for sexuality, as well as concepts of moral integrity and sexual pleasure are just as essential for the shaping of sexual relationships of young men and women as the knowledge being conveyed by national and international campaigns. Cf. (Dilger 2003).

[18] In the year 2001 around 9% of the region's adult population was infected with HIV. However, there had been no continuous HIV/ AIDS response in the villages until 2005 when an ARV treatment center was put in place by the government in collaboration with one of the private, mission-based hospitals in the area.

the differences in the quality of care and the availability of the care provided was determined above all by gender specific dynamics. The latter played a particularly important role with regard to the care situations of young women. In the patrilineal family structures of the research region, women and their children were considered part of the husbands' families following marriage. As such, their care in times of sickness or in the case of the death of their husbands was considered the responsibility of their husbands' relatives. In reality, however, these rules and expectations often represented the basis for tension and discussion across family networks: in particular with regard to young wives who became ill with HIV/AIDS, the question would be raised if they were "properly" married and if the marriage had been "correctly" confirmed through a dowry. Discussions concerning proper marriages—and thus the recognition of the status of a wife—were especially common concerning childless women as well as widows, whose claims on their husbands' inheritances would be shared not only with their children, but with their in-laws as well.[19]

On another level, relationships of care and support were shaped by the kinship-based politics of burial and belonging, which forced people who had worked and lived outside of their villages for extended periods to return to their rural homes when death was approaching. Questions concerning care and the subsequent burial—and especially the place of burial—were thereby potentially conflictive questions and reflected again on the dynamics of age, gender and belonging within patrilineal kinship networks.[20] Thus, while in some cases the care and the burial of male relatives raised questions concerning (unfulfilled) solidarity and kinship obligations, the situation of women was often more troubling to the families involved. Especially in the case of younger women who had been married to their husbands only recently and who had no children, or only a few at the time of their death, the question was posed to which family they actually belonged and who was responsible for their care and burial: their husband's or their father's family. Unmarried (or not formally married) women, on the other hand, were cared for mostly by their family of origin and buried on the compound of their brother-in-law who thus provided the deceased with the status of a co-wife.[21]

Finally, prior to the arrival of ARV the families in rural Mara dealt with HIV/AIDS illnesses by keeping silent about the infections and deaths of family members. Prior to the arrival of ARV, only very few HIV-infected men and women among my informants knew about their diagnosis and hardly any of them talked

[19] Cf. (Dilger 2005, 2006).

[20] Cf. (Cohen and Atieno Odhiambo 1992).

[21] On the liminal situation of (young) women in patrilineal kinship networks in Uganda, and the challenges this liminality entails for their burials in the time of AIDS, see (Whyte 2005). In Western Mara, conflicts and discussions concerning the burials of men and women in the context of HIV/AIDS were also driven by the concern that the spirit of a deceased person might seek revenge if ritual prescriptions were not observed. The danger was considered especially high from women or young girls who were not married at the time of their death. If they were buried within their father's compound they were said to attract evil spirits and unleash infertility among their female relatives.

openly about it. Testing and counseling was carried out in the local hospitals, but only for those patients who were suspected to have been infected with HIV by the health staff. Those patients who were found to be HIV-positive were often not informed about their diagnoses, and those who were, were sent home due to the high costs of nursing AIDS patients and due to beds in the local hospitals becoming increasingly over-occupied. However, while at the turn of the century the silence on the biological dimensions of the disease had become for people in Mara an integral part of referring to illnesses and deaths in the time of AIDS, this did not mean that there was no talk *at all* about the illnesses of dying community members or relatives. On the one hand, HIV/AIDS-related illnesses and deaths were the subject of multiple rumors that were circulating in the villages and that concerned the nature and origin of suffering—as well as the sexual relationships and networks that were its alleged root cause—in detail. The targets of this talk were carefully trying to prevent these rumors from spreading—sometimes even beyond death—and many people were hesitant to discuss their claims openly, especially if the person who was suspected of an HIV infection was a powerful and influential member of the community.

On the other hand, many individuals and families in Mara referred to HIV/AIDS in terms of other diseases such as tuberculosis or *herpes zooster*, or associated it with witchcraft and also *chira*, a disease that was said to be caused by the non-observance of ritual prescriptions, the symptoms of which were described as being very similar to AIDS (Dilger 2006, 2008). While at the time of my research not all people in Mara would have argued that *all* cases of HIV/AIDS were related to *chira*, in those cases where the connection was established this had immediate effects on the way treatment was sought for patients and how care and support were being organized within family networks (this being related essentially to the fact that *chira* was said to be curable with the help of local herbs).

22.4.2 Healing, Community and Care in a Neo-Pentecostal Congregation in Dar es Salaam

In rural areas as in urban centers of Tanzania the daily lives of people living with HIV/AIDS are often more complex than public health programs suggest. In particular in Dar es Salaam, Neopentecostal churches, which have seen drastic increases in the number of members in large sections of sub-Saharan Africa in recent years, have played an important role in the social, economic and religious life situations of people with HIV/AIDS. The *Full Gospel Bible Fellowship Church* (FGBFC) in Dar es Salaam in which I conducted fieldwork in 1999 and 2000 was founded in 1989 by Zachariah Kakobe, a charismatic bishop from Southern Tanzania who had earned his living as a musician and meteorologist before receiving his calling in 1980. Over the last twenty years, the church has established branches in almost all regions and districts of the country and counted more than 120,000 members nationwide in the year 2000. In 1999, the FGBFC caused a stir through its public

AIDS healings, which attracted 300–400 people a week and were hotly debated in the print media and among the public.[22]

For the members of the FGBFC I encountered during my fieldwork, the church became a source of hope mainly through its gospel of prosperity and, intimately related to it, the concepts of "awakening" and "salvation." According to Corten and Marshall-Fratani (2001) salvation in a Pentecostal church is "an ongoing existential project," which requires engagement in church activities and healing prayers in order to ward off attacks by diabolic forces as well as a break with many of the obligations church followers have towards their families (especially the "cultural" and "ritual" obligations which are associated with the central phases of life, i.e. birth, marriage and death).[23] In the case of the FGBFC, the church teachings required furthermore the abandonment of sinful lifestyles such as consumption of alcohol or engagement in extramarital sexual relationships. It was only if these (admittedly difficult) conditions were fulfilled that the manifold promises of salvation began to work in multiple directions. Thus, the gospel of health and wealth in the FGBFC promised not only material success and progress for those living in poverty. Salvation also meant the relief from all kinds of distress such as trouble at work or with the Tanzanian bureaucratic system, as well as from diseases such as infertility, cancer, high blood pressure or AIDS.[24]

Apart from the AIDS healings, which according to the church's bishop and his followers have been confirmed in some cases by biomedical tests, the church has established a network of mutual solidarity that provides help and support for members in times of need and crisis. At the time of my research, the church had established a dense network of small neighbourhood churches which comprised twenty to thirty members each and in which the idea of a "spiritual family" was promoted. This was defined in opposition to the worldly family and aimed to build a new moral community that was to disperse any doubts the church members might have about the righteousness of their path. This process of relation and community building was an ambiguous process which implied a high potential for intra-familial conflict, stemming both from unsaved relatives who tried to make church members depart from the path of salvation, as well as from the church followers who persistently urged their families to give up their "dark" and "sinful" ways. However, the FGBFC was described to me by its members not only as a source of conflict, but also as a beneficial network of care and support that flexibly reacted to the needs of its individual followers. Especially in cases of serious illness the charitable acts of other church followers went far beyond immediate acts of caring or nursing and often included arrangements of funerals, etc. The provision of such acts of solidarity had become particularly beneficial for the mostly female members of the church who were mainly young to middle-aged women with low educational status who had migrated to Dar es Salaam in search of employment

[22] Cf. (Dilger 2007).
[23] See also (Meyer 1998).
[24] Cf. (Dilger 2007).

or business opportunities during the 1980s or 1990s. To these women—as well as to the male members of the church most of whom had a similar social background—the FGBFC was appealing essentially because it offered a space of hope, stability and moral orientation in the urban context, which was experienced as increasingly risky and ambivalent.

What can be drawn now from these two case studies on the FGBFC and on kinship networks in rural Mara? As I hope to have shown, there may be significant gaps between what the "empowered individuals" of transnationally designed health programs—including subjects formulated predominantly by NGOs—and people who perceive of themselves mainly as members of kinship and other community-based networks "know" about illness and well-being in the times of AIDS. People in Tanzania, who may have a range of resources at their disposal and who may depend in their decisions on a variety of social and cultural settings and relationships do not always act in accordance with public health messages or with regard to the greatest benefits to their own (or others') biologically-defined health. At the turn of the century, individual and collective behaviors in the era of AIDS were not only constrained by growing economic pressures and the lack of access to healthcare services, which had been triggered by neoliberal economics and political reforms in the health sector over the previous two decades. They were also rooted in the logics of community and kinship politics and in the moral, cultural and religious priorities that people had with regard to the persistence of social relationships in and beyond the context of death and suffering. The exclusive focus on lifeworlds that are promoted and represented by state actors, nongovernmental organizations and humanitarian interventions would have revealed only a partial view of the complex social and cultural processes that have come to shape the knowledge, experience and practice surrounding HIV/AIDS in Tanzania and other parts of sub-Saharan Africa. Consequently, I would argue that if we think critically about notions of citizenship and self-care in relation to HIV/ AIDS, we need to take account of the complex relationships between power, experience and practice which have shaped people's identities and subjectivities in the wake of globalization and the emerging epidemic.

22.5 Conclusion: Knowledge, Practice and (Bio)Power in the Context of Globalization

In the course of doing fieldwork in Tanzania, I was often struck by the fact that while people were generally well aware of how HIV is transmitted, how to protect oneself from infection, or how one should *supposedly* behave towards people with HIV/AIDS, their actual behaviors concerning sexuality or HIV/AIDS-related illnesses and deaths were often directly opposed to this information. Thus, while health messages about HIV/ AIDS were widely acknowledged among people in Tanzania even before the introduction of antiretroviral treatment, social and cultural practices surrounding sexuality or episodes of HIV/AIDS-related illnesses and deaths were shaped less by information and knowledge drawn from governmental or nongovernmental HIV/AIDS programs, but had become intimately intertwined with people's concerns about familial, social and economic developments in the context of modernity and globalization, and the moral and reproductive order at large. The few examples I have given in the previous section should suffice to state that over the last two decades individual and collective behaviors in the era of AIDS have not only been constrained by growing economic pressure and uncertainties triggered by neoliberal economics and political reforms. They are also rooted in the logics of community and kinship politics and in the moral, cultural and religious priorities that people have with regard to the persistence of social relationships in the context of death and suffering.[25]

In contrasting the different ways in which individuals, families, communities and a wide range of governmental and nongovernmental actors have come to deal with HIV/AIDS in rural and urban Tanzania, three issues are interesting to observe. All of these issues shed light on the way in which the relation between knowledge, practice and (bio)power has been shaped and reconfigured in the context of globalization and neoliberal reform processes over the last two decades. First, the analysis above has made clear that the various contexts in which people have come to act on HIV/AIDS in Tanzania imply shifting understandings of the causal connection between knowledge and practice. While earlier approaches in HIV/AIDS prevention were based on the "rational actor model" and have assumed that the availability of knowledge (in the sense of information) translates *necessarily* into practice (in the sense of behavior), more recent approaches have adopted a broader view of this connection. Thus, approaches that are based on the notion of empowerment acknowledge that biomedical and public health knowledge acquire meaning only in relation to the larger *contexts* in which individual behavior is supposed to materialize. Addressed are in particular the (gendered) relationships between sexual partners, emotional states like fear, love or hope, the dynamics in (nuclear) families, and—to a minor extent, the socio-economic and legal conditions that shape the lives of individual actors in contemporary Tanzania. Excluded remain, however, the larger transformations in politics and healthcare in the country, alternative notions of illness and healing, and also the dynamics of kinship and belonging in relation to extended family networks and religious communities in urban and rural settings. As argued above, these latter aspects play a crucial role in shaping individual and collective behaviors and practices in relation to HIV/AIDS in rural and urban areas.

Second, the different types of knowledge, practice and experience that have emerged in the context of globalization and HIV/AIDS in Tanzania are inseparably intertwined with different types of subjectivities and the reflexive self which are in turn built around shifting concepts of the person and gender. Thus, the approaches and interventions of nongovernmental organizations perceive of their target groups and clients as largely autonomously acting individuals who, in the

[25] Cf. (Dilger 2005, 2008; Dilger and Luig 2010).

case of women, need to be empowered socially, economically and legally in order to be able to make healthy and responsible decisions. Men, on the other hand, are seen as economically, socially and legally privileged and as being largely in charge of most of the decisions relating to their partnerships and families. Only in recent years have NGOs and local interest groups come to reflect critically on socially constructed modes of masculinity and male sexuality and have emphasized the need for men's "cultural empowerment," which might enable them to assume a "positive" gender role as responsible husband, son, father and sexual partner.[26]

Such discourses and images contrast with the expectations, roles and responsibilities that are formulated for the behaviors of men and women in other areas of life in Tanzania. In the patrilineal kinship networks in rural areas, the well-being of individual men and women is often closely interwoven with the fate of their—and in the case of women their husbands'—nuclear and extended families. Illness and suffering are often understood here as a reflection of the wider state of (gender and age-specific) social relations which are perceived as being disturbed by globalization and migratory processes and which need to be worked upon in order to ensure individual and collective well-being. In contrast, Pentecostal churches like the FGBFC in Dar es Salaam, offer new spaces of solidarity and attachment—especially for women—and thus provide an alternative to the male-centred kinship networks of rural and urban areas. Such churches often pursue a highly conservative gender ideology, however, which is centred on the nuclear family and which expects decency and submissiveness of women towards their husbands. It is important to emphasize that these different types of gendered subjectivities and concepts of the person as outlined here are not mutually exclusive. People's lives are often shaped in relation to different urban as well as rural localities and social settings through which they are exposed to shifting, and often conflicting, types of expectations, knowledge and values.

Finally, the way knowledge, truth and meaning are produced and reproduced in relation to HIV/AIDS in various settings of Tanzania has been shaped by the context of global development and health restructuring over the last two to three decades, as well as by the multiple iconographies and textual representations that have become part and parcel of the process of producing meaning and truth in the era of globalization. On the one hand, globally driven development precludes the integration of certain types of truth and knowledge into health interventions, a fact that is amply illustrated by the various images, texts and statistics produced by governmental as well as nongovernmental actors in the form of flyers, booklets and reports. In particular, the multiple moral conflicts relating to decisions concerning health and sexuality—but also people's alternative knowledge and experiences concerning illness, healing, death and mourning—are seldom addressed by internationally funded interventions and programs. Thus, while "local knowledge" and experiences are highly valued in other areas of development work in Tanzania (especially in agriculture and more recently also in the field of tra-

[26]For the discourse on the "new men" in South Africa, see (Morrell 2001).

ditional medicine), HIV/AIDS interventions in the country have often engaged a modernizing approach that reproduces established dichotomies like "tradition vs. modernity," "belief vs. knowledge" and "religion vs. medicine and science." In this context, local knowledge, experience and practice, which have become partially represented in local Swahili publications and cartoons, are often branded as "superstitious," "harmful" and "backwards."

On another level, and related to this, the production and dissemination of knowledge, meaning and truth in the neoliberal era have been shaped by the growing disjuncture between the practices, experiences and ideas of (internally further differentiated) families and communities, on the one hand, and the expectations and values that are promoted by the (equally differentiated) HIV/AIDS industry, on the other. Thus, this text has shown that the promises and services of NGOs and FBOs have had an impact on the lives of many individuals, some of whom have benefited from the new funding arrangements that have also opened up new avenues into the globalized health order on a personal level. Many others, however, rely on knowledge and relationships beyond the biomedically defined health settings, and try to act on their bodies and illnesses by drawing on a wide range of resources that have emerged, and have been transformed, in response to HIV/AIDS and shifting social and political-economic conditions. In conclusion, I would like to argue therefore that this disjuncture has become reflective of the way in which the circulation of medicine and biopower in the neoliberal era has been shaped by the way global capital and development are "hopping" over sub-Saharan Africa (Ferguson 2006) thereby reconfiguring social, economic and cultural constellations on the continent in only fragmentary ways. Thus, while the production and spreading of biopower in Tanzania have become embedded in globalized channels of funding, which govern "regimes of truth and knowledge" in the context of HIV/AIDS and structural adjustment in often contradictory ways, the state and its institutions—as well as the nongovernmental actors that have become complementary to them—have only limited ability to establish and exercise biopolitical authority in a *pervasive* way. Under these conditions, many Tanzanians have developed a critical sense of their government's ability to control the living conditions of its citizens on a daily basis, thus looking for "collective solidarity" and "moral beneficence outside of the state altogether" (Ferguson 2006, 85). In this regard, moral knowledge, practice and experience—and the various forms of sociality and belonging that have been built around them—have remained of crucial importance to individuals, communities and families in making sense of the transformations and challenges related to globalization and responding actively to the suffering associated with HIV/AIDS.

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Chapter 23
The Transformations of Knowledge Through Cultural Interactions in Brazil: The Case of the Tupinikim and the Guarani

Circe Mary Silva da Silva and Ligia Arantes Sad

23.1 Introduction

This chapter examines and analyzes some of the questions from current discussions in the field of intercultural studies on the basis of a synthesis of aspects of the Guarani and Tupinikim cultures in the Brazilian state of Espírito Santo.[1] We would like to make the voices of the members of those native Brazilian ethnic groups audible; we would like to let them speak so that they themselves can present those aspects of their culture that have been, or not been, altered through contact with other cultures.

Our focus on the school education that has been developed for those ethnic communities aims to respond to a demand from the communities themselves. Since Tupinikim and Guarani villages have formal schools, it has proven necessary to develop an educational curriculum that is equivalent to that of the non-native populations, and therefore valid from the point of view of the educational system.

Having been invited to participate in this development process, we looked for ways to preserve and give value to the Tupinikim and Guarani cultures within a specific curricular project. The goal of such a project is to strengthen indigenous identity and to take into account the non-native knowledge that is necessary to live together in a more global society.

In order to carry out the task, we engaged mainly in documentary and field research aimed at recovering those populations' culture. At the same time, we promoted projects of continuous education in collaboration with native educators and non-native partners involved in curricular development. The chief objective of the "action research" methodology is to integrate the native Brazilian cultural perspective with the symbolic, technical and scientific knowledge transmitted by the school.

Thus, for example, the mathematical concept of symmetry, present in the formal school curriculum, could be introduced on the basis of basket-weaving and

[1]The text was translated from Portuguese by Rafaela Teixeira Zorzanelli.

body painting, ancient indigenous practices that are still alive today. We therefore agree with Peter Damerow:[2]

> It is not a different mathematics that is created but rather a different approach to it. Thus, a basic requirement is claimed. How can a "poor" country afford to waste and neglect the educational potential of its people by following the didactic model of a foreign culture in which experiences are required that are not made in their own culture! How else, but by referring to experiences made within their own culture, can educators acquire the necessary confidence that allows them to act in a way that does not follow prescribed school rituals.

In order to understand the intercultural processes that bring about transformations and continuities, we examined how the knowledge involved in such practices is produced through meanings and senses manifest in the language, material culture and religion of the Tupinikim and the Guarani.

Within such an intercultural context, we took into consideration that local knowledge is not totally isolated from global knowledge. In other words, the local should be understood as part of the global. We agree with the idea that "local" knowledge can be seen as part of global knowledge in which different types of knowledge are negotiated, appropriated, and (re)distributed by a multitude of actors.[3] There are no precise boundaries between the local and the global because what we call "local knowledge" is local from our point of view and not from that of indigenous populations. Moreover, the local is perennial, since intercultural contact transforms it in such a way that it is difficult to determine if what we characterize as "local" corresponds to that characterization, or should already be considered part of the global context. In short, it is not possible to speak of "local" and "global" in an absolute or dichotomous manner.

These ethnic groups are part of what we term "local"; as minorities of the non-native population the Tupinikim and the Guarani possess only relative power and to a certain extent depend on the dominant non-indigenous culture that is imposed on them. It is in awareness of these cultural differences that one can observe and analyze negotiation issues and changes in what we call global and local knowledge.

The population of the two native Brazilian communities in question, altogether around 2000 people, is small in comparison with the approximately 3,3 million who inhabit the state of Espírito Santo. Moreover, the Tupinikim and the

[2]The original text reads "Nicht eine andere Mathematik wird entworfen, sondern nur ein anderer Zugang zu ihr. Eine Mindestforderung wird so reklamiert. Wie kann ein 'armes' Land sich auch noch leisten, die Bildungsvoraussetzungen seines Volkes zu vergeuden und zu entwerten, indem es didaktische Vorbilder einer fremden Kultur kopiert, in denen Erfahrungen vorausgesetzt werden, die in der eigenen nicht gegeben sind! Wie anders als durch das Anknüpfen an die Erfahrungen in der eigenen Kultur könnten Lehrer jenes Selbstvertrauen gewinnen, das nötig ist, um anderes zu tun, als vorgegebene Schulrituale zu vollziehen" (Damerow 1990, xv).

[3]See chapter 16.

Guarani occupy a small geographic area. They inhabit a cultural space the non-natives call an indigenous reservation,[4] a limited territory owned by the federal state and organized so as to allow the communities to live in close contact with nature according to their traditional notions and beliefs. That space, however, is not free from external interference. For example, almost every village has medical stations, public telephones and temples of various religious groups.

The production of knowledge and its negotiation with the non-native is part of complex interactions between the individuals involved in the global context to which the local belongs. But the process of competition and sharing between native and non-native societies has brought about the modification of traditional ways of living, as well as technological innovations that have been assimilated into the villages, such as the use of televisions and refrigerators. The introduction of industrialized foods is also indicative of how habits and traditions have been abandoned and even replaced.

What is left, then, of Tupinikim and Guarani local knowledge? What has been modified or substituted in the globalization process? Finding answers to these questions is a challenge that requires exploring the different domains of knowledge characteristic of each group. This is consistent with Jürgen Renn's observation that:

> Our situation today may rather be understood as the result of historical process that comprise all dimensions characterizing modern globalization processes, each with its own, peculiar constellation of economic, political, technical, cultural, ethic, and epistemic means of cohesion. The study of these historical processes may therefore help to understand the present situation, avoiding the reduction of its complexity […]. (Renn 2007, 43)

This chapter will examine several relevant aspects of the negotiations and assimilations between local and global knowledge within the sociocultural context the natives share with the non-natives. The text comprises five parts. The first part describes historical aspects of the Tupinikim and the Guarani, as well as their present-day circumstances. The second part concerns their culture, religiosity and language. The third part deals with knowledge embodied in their art, crafts, food, clothing, habitation, instruments and utensils, medicinal plants and techniques of subsistence. The fourth part of this article examines the combination of formal education with an indigenous education based on the oral transmission of knowledge and on the imitation of practical activities. The fifth and final part explores the transformation of material culture and social and political relations caused by external influences, as well as the interactions of native ethnic communities with the larger development of Brazilian society.

[4]According to the *Estatuto do Índio* (Law 6.001), promulgated in 1973 and still valid today, Indian reservations (*Terras Reservadas*) consist of land the Federal Government reserves for Indian use, not necessarily land that was traditionally inhabited by native ethnic groups.

In addition our analysis aims to make systematic contributions to the continuous training of Guarani and Tupinikim educators, so that the communities themselves can become involved in the elaboration of a school curriculum that includes aspects of their own cultures.

23.2 A Glimpse into History

Anthropology continues to provide information on ever-older human groups; cave paintings around 12,000 years old have been discovered in the Serra da Capivara in the state of Piauí. The research of Perrota and Mendonça date human presence in the state of Espírito Santo to 5,000 BCE (Coutinho 2006, 74). At the time of the Portuguese arrival in Brazil in 1500, the territory was inhabited by groups identified as belonging to the Tupi-Guarani.

Authors such as Alfred Métraux (1950), Arthur Ramos (1943), José de Lima Figueiredo (1949) and Florestan Fernandes (1964) agree that the Tupinambá were one of the most important Brazilian native ethnic groups, and that almost all other indigenous groups from the coastal area stem from them. Etymologically, "Tupinambá" means "the descendants of the founders of the nation," or "the main fathers."[5] The Tupinambá are related to various other ethnic groups, such as the Goitacazes (*Waitaká*), the Tamoios, the Temiminós and the Tupinikim. In the sixteenth century, the Tupinikim occupied two areas, one situated between the present states of Bahia and Espírito Santo, another further South, between Rio de Janeiro and São Paulo.

According to Figueiredo (1949) the first natives Pedro Álvares Cabral encountered were Tupinikim. Figueiredo thinks the Portuguese were fortunate to meet a group characterized by loyalty, hospitality, docility and diligence. Indeed, these features helped conquerors to dominate the natives and use them in their interest. For the native populations, however, that meant the beginning of a progressive assimilation to the non-native culture, and the subsequent loss of their own. Serafim Leite (2000, vol. 1, 230) asserts that in the sixteenth century there were in Espírito Santo four large indigenous villages under Jesuit tutelage, and six additional ones made up of natives who had not been catechized. According to the same author, after the expulsion of the Jesuits from Brazil in 1759, native communities remained under the domination of the non-Indians, employed as forced labor in agriculture, construction, and so forth, initially without remuneration and later on extremely low pay. Many natives were imprisoned to prevent their escape (Leite 2000, vol. 6, 178–179).

A critical reading of such historical narrative, written from the dominators' point of view, highlights the sociocultural elements that have been omitted or ignored. To relate the history of the Brazilian native communities to a reflection on the indigenous educational context therefore means more than simply preserving

[5] The original text reads "os descendentes dos fundadores da nação," or "pais principais" (Métraux 1950, 11).

a traditional and well-known history, such as that written by Serafim Leite: it should open up our historical vision and bring to it the intercultural perspective that is indispensable in carrying out the curricular transformations demanded by the Indians who inhabit *capixaba* territory (i.e., Espírito Santo).

The Tupinikim population in the area between Espírito Santo and Bahia has been estimated to 55,000 persons in the early years of the colonization of Brazil.[6] As inhabitants of coastal regions, the Tupinikim suffered considerably under occupation. After their arrival in Brazil the Jesuits created settlements in Tupinikim territories. According to José Maria Coutinho:

> Though marginalized in the national and even state context, the early history of the Aracruz municipality was not isolated from the more general context of the Portuguese colonization of Brazil. One of the oldest Brazilian towns was established there—the third in Espírito Santo after Vila Velha (1535) and Vitória (1551)—and all were created to defend the territory against French incursions, as well as to counter the natives' resistance. In the Aracruz municipality, the Portuguese established Aldeia Nova in 1556. (Coutinho 2006, 109)

In 1953, the state government of Espírito Santo created the Comboios Biological Reserve, whose borders include the totality of the lands traditionally occupied by the Tupinikim. In 1976, the environmentalist Augusto Ruschi proposed to the FUNAI[7] to transform the biological reserve into a reservation that would host the "remaining Tupinikim."

The land reductions imposed on the indigenous peoples by political and economic interests prevented the traditional alternation of crops, and led to a concentration of families in villages such as Caieiras Velha, Irajá and Comboios, which still exist today. Some cultural elements, such as the Tupinikim home, still present traditional features; at the same time, as we shall see in the third part of this article, new features visible in the villages derive from the contact between the natives and the non-natives.

Historically, the Tupinikim lived in Espírito Santo before the Guaranis, who began building their own villages in that state only in the 1960s. Egon Schaden (1977, 10) divides the Guarani into three subgroups, the *Kaiova*, *Nhandeva* and *Mbya*, according to their linguistic and cultural features. The *Mbya* are the ones who have moved the most and therefore present the widest territorial scattering. Part of the Guarani-*Mbya* migrated from the southern regions of Brazil; they were guided by the spiritual leader *Tatatï Yva Re Ete* whose dreams, considered to be a divine revelation, indicated the ideal location for her people. That place, known as

[6] Information from www.ibge.gov.br/brasil500/indios/numeros.html.

[7] FUNAI is the *Fundação Nacional do Índio* (National Indian Foundation), a federal agency that defines and applies Brazilian policies regarding native peoples in conformity with the 1988 Constitution.

Tekoa Pora in Guarani, extended the areas of the Atlantic Forest (*Mata Atlântica*) already inhabited by the Mbya.

The group *Tatatï* led in the search for the "land without evil" (*terra sem males*), left Rio Grande do Sul and, for a period of almost thirty years between the 1940s and the 1970s, traveled through the states of São Paulo, Rio de Janeiro, Espírito Santo and Minas Gerais (Ciccarone 1996, 9). In 1962, six families arrived in Espírito Santo; the group grew, and according to a FUNAI census of 2005, the indigenous Guarani population comprised at that time about 237 people.

The main Guarani village, *Aldeia de Boa Esperança* (Village of Good Hope), was established in 1979 about seventy kilometers north of Vitória in Aracruz. Although their world of gods is distinctly masculine, women play a prominent role in the family life and daily habits of the *Tekoa* of Boa Esperança and are respected in their sacred role as child bearers.

Caieras Velha and Irajá, two other Tupinikim settlements, are to be found in the neighboring region. The area that includes these three villages as well as access to the Piraquê-açu river extends eastwards to the coast, and westwards to a small native forest whose boundaries are negotiated by the Guarani-Mbya and the Tupinikim. The arrival in 1967 of the cellulose factory Aracruz Florestal and the financial interests of the mining company Vale do Rio Doce (since renamed Vale) marked the beginning of land acquisitions and conflicts caused by the invasion of forest areas, the cutting down of native trees, and the degradation of natural resources.[8]

From a historical point of view, humans are not mere repositories of information and knowledge passed on by their predecessors through practical and intellectual activities. The ethnic groups to which we refer here not only preserve their ancestors' experience, which is essential to their survival and to the existential continuity of their identity, but they also adapt to the larger cultural context in which they live in ways that are useful to them.

23.3 Identity, Language and Religion

The goal of connecting identity, language and religion is to recover the cultural foundations of the Tupinikim and the Guarani cultures so as to foster their appreciation and dissemination—and thereby their preservation—by means of school education. The proposal of a differentiated curriculum aims at satisfying a demand of indigenous communities, shared by the non-native groups who pursue an intercultural approach to education, for fair and harmonious integration. We adhere to Coutinho's position (Coutinho 2006, 53) when he asserts that interculturalism consists in the exchange of different cultures who agree to look for common solutions to disagreements and social injustices. To propose an intercultural education

[8] On its website Vale presents itself as a global company with a passion for transforming mineral resources into prosperity and sustainable development, see www.vale.com.

therefore implies reconsidering educational practices so as to take into account and respect the differences between the sociocultural groups involved in the process.

The dialogical negotiation essential for such a process takes place through an interweaving of meanings originating in different languages; although these may be different, they are not incommensurable given that the language used in Brazil has incorporated elements of the Tupi-Guarani linguistic family. Even though the Tupinikim and the Guarani inhabit the same region and belong to the same linguistic family, their languages and religions are actually quite different. These differences contribute to the differentiation of other sociocultural dimensions, and that is why they are presented separately here.

Moreover, the languages considered are constantly evolving and interact with Portuguese, Brazil's official language, which affects and is in turn influenced by indigenous languages. We agree with Mikhail Bakhtin (1984) when he considers language as a system of norms in constant and uninterrupted transformation. Linguistic transformations caused by exchanges, as well as by bilingualism and multilingualism, impact on education, society and culture in general. In addition, multilingualism can be understood as a critical factor in globalization processes (Renn 2007, 44).

23.3.1 Guarani

The Guarani themselves claim that being Guarani amounts to being religious. Religiosity plays a crucial role in their culture and Guarani individuals from an early age manifest a strong sense of identity based on religion and their mother tongue, two inalienable characteristics. While other native Brazilian ethnic groups have partially or completely lost their languages and religions, the Guarani have long preserved them and they remain relatively unaffected by intercultural processes. Among the Guarani it was always desirable to maintain traditions, though this was not always possible, as during the time of the Jesuit missions (sixteenth to eighteenth centuries), when the non-native culture was imposed on them.

The word *guarani* is written with oxytonic stress: *guaraní*, meaning warrior or warring. As already mentioned, the Guarani language belongs to the Tupi-Guarani family, which is spoken by several indigenous peoples of Brazil, Argentina, Bolivia, Uruguay and Paraguay (the country in which it is an official language alongside Spanish). From a phonetic point of view, it is to be noted that most Guarani words are oxytonic.

The Guarani believe that language (*ayvú*) has a divine origin. According to Schaden (1962, 115) they think that the primordial function of the soul is to give humans the gift of language. The creator god *Ñanderu* also gives speech (*ñée*). Unkel (1987) explains that dialects define membership in a tribe; those who do not speak the tribe's dialect are therefore considered foreigners. The same author describes the Guarani's scorn of Portuguese Christian names; according to the Guarani, each child has an indigenous name before birth, which he or she adopts as a legitimate name.

As Jürgen Habermas rightly observes,

> the medium of language does not facilitate first and foremost the description or affirmation of facts; it equally serves for giving commands, solving riddles, telling jokes, thanking, cursing, greeting and praying. (Habermas 1992, 62)

The *Mbya* Guarani language remains alive and is orally transmitted to the children in the villages, who also learn and speak Portuguese quite fluently. Although written Guarani is little used, the children from the villages learn how to read and write in their mother tongue, and use it as a means of expression.

Pre-school Guarani children only use and communicate in their mother tongue. In school, learning Portuguese amounts to learning a foreign language that is unfamiliar in comparison to the mother tongue. Vološinov writes:

> the native word is one's "kith and kin"; we feel about it as we feel about our habitual attire or, even better, about the atmosphere in which we habitually live and breathe. It contains no mystery […]. (Vološinov 1973, 75)

At school, children become bilingual; this differentiates them from children who attend non-indigenous schools. When they write, they mix Guarani and Portuguese, as can be seen in Figure 23.1, which shows a page from the notebook of a third-grade girl from a school in Aldeia Boa Esperança.

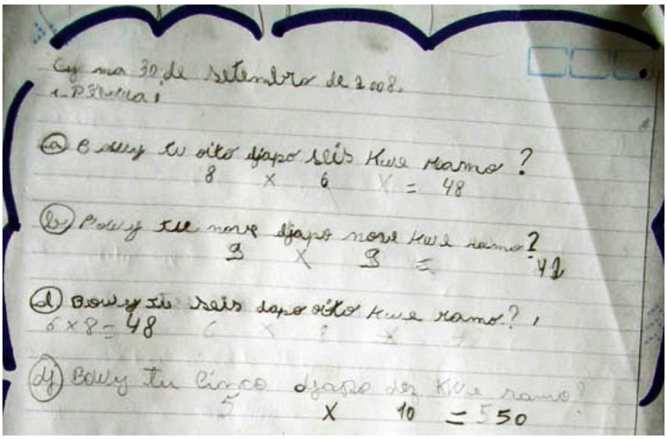

Figure 23.1: Page of a notebook of a third-grade Guarani child from Aldeia Boa Esperança. (Photo by Silva, 2008)

The page includes both Portuguese and Guarani. We see on the third line the sentence, *"Bowy tu oito djapo seis kwe ramo?"* In Portuguese, *"Quantas vezes* *daria se o oito a gente pulasse seis?"* (How much would it amount to if eight were added six times?). The Guarani schoolteacher corrected in the following way: *"Bowy kwe oito djapo seis ramo?"* In the teacher's translation, *"oito a gente pulasse seis"* ("if we added eight six times") designates multiplication as six successive additions of eight. It is interesting to note that even when they know the numbers in Guarani, they name them in Portuguese. In the classroom, there is a poster with Guarani numbers (Figure 23.2).

The ethnologist Diana Green (1997, 180) explains that Brazilian indigenous languages offer a variety of numerical systems, on the basis of two, three, five, ten and up to twenty, with logical-analytical or even holistic interpretations that may differ depending on the context. The example of Figure 23.2 presents a logical-analytical system of basis five.

The natives and non-natives who are in contact with each other exert a mutual influence through actions that are mediated by language.

Moreover, language plays a fundamental role in the understanding they gain of their own actions, since learning one's mother tongue goes hand in hand with the development of consciousness and action. Language is part and parcel of that development and moves together with it. As Bakhtin (1984) notes, language is not transmitted as a finished product from generation to generation, but is constantly evolving.

The Departments of Education of the different Brazilian states, as well as the federal Ministry of Education are currently supporting a number of programs for the introduction of Guarani into village schools.

Tupi-Guarani is the indigenous language group most studied in Brazil, Bolivia, Paraguay, Argentina and Guyana. Its study began with the Portuguese and Spanish colonizers in the sixteenth century, and today there are online dictionaries for both ancient Guarani and the current dialects.

Religion plays a fundamental role in Guarani culture. The Guarani religion assumes the existence of several gods and a relationship to nature. *Ñanderu—Tupã*—is the main god, the god of power. Thus, the *pajé*, a prominent member of the tribe, is most often a medicine man. João Carvalho, Karay Mimbi son of Tatati explains:

> God never dies. He becomes old during the cold period, so he turns old, and when summer arrives, when the trees and fruits flower, God becomes new again. He turns old and then returns here, new again. (Ciccarone 1996, 54)

Such an explanation highlights the relationship between God, nature and human beings. For the Guarani, important decisions proceed from revelations their religious leaders receive in dreams. Vision is a gift, a vocation, a divine revelation that implies an active process of attaining the true vision by means of dreams. Dreams are the image repository and subjective experience of those from whom knowledge and power proceed (Ciccarone 2001, 16).

Figure 23.2: Detail of a poster in the third-grade classroom of the Guarani school of Aldeia Boa Esperança. (Photo by Silva, 2008)

The Guarani hierarchy of gods is headed by *Ñanderu*, who was their creator and gave them divinity. He created *Karaí Ru Etê*, god of fire who lives in the East; *Djakairá Ru Etê*, god of fog and spring who lives in the North; *Tupã Ru Etê*, god of rain and thunder who lives in the West (Schaden 1982, 10). The village elders know how to position themselves and to relate space orientations to a given god. As the educator Mauro Luiz Carvalho told us:[9]

> The process of reaching the main god includes going through a succession of special places indicated by the gods. The most religious persons go most directly. The house of prayer is always directed towards the god Nhanderú ou Tupã, god of the sun, who illuminates our earth and our soul, driving away the evil of darkness. The same god also illuminates inside the house of prayer. The ideal thing is to have all the houses orientated towards sunshine, as the house of prayer.

The Guarani religion developed through resistance to pressure from external cultures. Together with language, it is a key element of Guarani identity and expression, and serves to preserve the group's unity. Religion permeates the Guarani's entire way of life, from the most daily things, such as food, planting techniques or the construction of houses, to forms of expression such as music, dance and art, as will be discussed later.

The Guarani's religious rituals include music and dance. Several rituals are carried out daily in the villages at two different times: the *xondaro*, warming up and preparation of the body, and the *porahéi*, songs and dances asking for peace to all Indians and the white people who want to help them. The *xondaro* is as well a dance relating to defense, and is therefore also a part of the daily life of the villages.

23.3.2 Tupinikim

In contrast to the Guarani, the present-day Tupinikim of Espírito Santo have lost their native Tupi language as well as their religion. At the time of the arrival of the Portuguese, the Tupinambá and the Tupinikim practiced a religion strongly linked to nature, the essential basis for their survival. They were henotheists, since they believed in one supreme god, but worshipped several minor deities (Coutinho 2006, 90). Little by little, through contact with the non-Indians, they assimilated the conqueror's culture, to the point of no longer communicating in their own language. They thereby lost many of the meanings of their traditional religious beliefs. Though identified as Tupinikim due to their particular biotype, they have entered a process of miscegenation through marriage with non-Indian partners.[10]

In the *Dicionário Etimológico da Língua Portuguesa* (Da Cunha 1986), the term "Tupinikim" has various spellings: *Topinaquis*, *Tupinaquis*, *Tupin-anquins*,

[9] Interview with Mauro Luiz Carvalho, Guarani educator, 2007.
[10] This observation is confirmed by Teresa Goulart (1975, 30–33).

Tupiniquins. According to the historian Varnhagen, *Tupi* means “next,” or “next door neighbor.” In the past, the Tupinikim spoke the coastal Tupi language, which belongs to the Tupi-Guarani family. Until the end of the seventeenth century, Brazil’s “official” language was Tupi-Guarani alongside Portuguese. In 1759, under the influence of the Marquis of Pombal,[11] the Portuguese crown prohibited the hybrid language, blaming it for disrupting communication and negotiations between Portugal and its Brazilian colony. Punishments were even imposed on those who did not speak and use Portuguese. This led to a decline in the usage of aboriginal languages, particularly in the coastal areas, where the control of the metropolis was most strongly exerted, and where most commercial exchanges took place. The passage of time and the interactions between the Tupinikim of the Aracruz villages and the non-Indians of the same district eventually led to the almost complete abandonment of Tupi, even though some words and expressions persisted. Thus, little by little, the Tupinikim ceased to speak their native language; they are presently in the process of recovering it through the introduction of Tupi in village schools.

For the Tupinikim, God and nature are one and the same.[12] They believe the forest is like a spiritual temple, and unanimously think that rivers and waterfalls have a body and a spirit. In turn, animals can carry messages; the *“kauan”* bird, for example, illuminated by God, can announce imminent death. The pajé was the tribe’s priest and was endowed with great powers that enabled him to function as a guide, healer, educator, seer and sorcerer. He exerted influence on the chief and on many occasions presided over official rituals and ceremonies. Since he was also capable of driving away evil spirits, he was also considered a shaman. As described by foreign travelers such as Hans Staden, the Tupinikim religion included cosmological knowledge. According to Coutinho (2006, 92) the Tupinikim knew the Southern Cross constellation, which they called *kuruçá*, meaning “cross” in Tupi, as well as several planets, such as Venus, which had two names, *pirapanema* (evening) and *jaceí-tatá-açu* (morning). Brazilian Indians generally give considerable importance to the constellations of the Milky Way, called in Guarani *tapi’i rapé* (the road of the tapir) (Afonso 2006).

After the arrival of Europeans on the American continent, and especially through the Jesuits’ missionary work, the natives’ beliefs were repressed and Christianity was imposed on them. After that period there were no major confrontations between the religions of the Indians and the Christians. This suggests that Egon Schaden (1982) is right to argue that living peacefully and accepting the foreigners’ religion was perhaps the natives’ strategy for preserving their own beliefs and values.

This kind of process of cultural transference in the domain of religion continues until today. In the villages there are churches of different Christian denominations

[11] Sebastião José de Carvalho e Melo, better known as Marquis of Pombal, played an important role in the government of the Portuguese King Joseph I (1750–1777).

[12] What Coutinho (2006, 90) characterizes as a *religião de integração* (integrative religion).

(Catholic and several branches of the Evangelical). The Tupinikim see no contradiction in following the religious precepts of the "white man's" church, and at the same time their own native beliefs. In her M.A. thesis on the ideas and attitudes of Tupinikim educators vis-à-vis mathematics, Dóris Reis de Magalhães records the following narrative, transmitted by an inhabitant of the Pau-Brasil village:

> I attend one of the religious temples built in our village, and I believe in the words of the Bible and the minister's teaching. [...] I think that our belief in God has something to do with some legends we know until today, and which many of us believe as true. I don't know. What I do know is that when I'm in trouble, I go alone into the forest, always barefoot, and I talk with the plants, with nature. It's there that I cry, sing, talk or laugh. I don't feel alone because I am part of the place. When the tree leaves fan me I have the feeling of being valued, as if the trees were applauding me. The forest values me because it knows I value it. I am part of the forest, like each tree, each plant, like the earth that encloses the forest, you understand? I don't know what happens to me when I'm in the forest. My soul becomes light. I know and feel I belong to that nature that surrounds me. I don't feel superior even to a leaf. Spiritually, I feel happiness and inner peace, close to God because nature is God. It's there that I make my personal reflections and speak with nature, which is the same thing as speaking with Him. Sometimes I go to the forest sad or stressed out, and when I return, I feel renewed. For me, the forest is also a religious temple. And I'm not alone to feel that way. Many of us Tupinikim feel and say the same thing. (Magalhães 2007)

The Tupinikim assimilation of other religions and the loss of their mother tongue, replaced by Portuguese, has led to a weakening of their ethnic identity. In contrast, the Guarani people were able to keep their religious beliefs and native language, and have thus preserved their identity more completely.

23.4 Indigenous Practices

Traditional Tupinikim and Guarani knowledge is expressed orally, as well as in painting, music, crafts and dances. It is also embodied in the way they build their houses, cook, prepare medicines, dress, as well as in their tools and general techniques. We agree with Norbert E. Wilhelm (2008, 422–423) that "the fact that we now use other technologies does not mean that traditional knowledge was primitive." For example, Indian crafts have their own beauty, with standards for the use of raw materials and well-systematized techniques whose cultural dimensions cannot be considered inferior or of less value than those of other cultures. Similarly, the construction of the external walls of houses, in which raw materials such as bamboo and mud are used, demonstrate the use of natural elements available in the local surroundings; they can therefore be understood as particularly ecological, not presenting any problem of recycling. Nevertheless, since the natives are poorer than the other groups, their technology is considered primitive, and its values and potentials are not taken into consideration.

23.4.1 Tupinikim

Together with religious beliefs, legends play a significant role for the Tupinikim. One of the most important ones is the "legend of the Saci," which has different versions and which many believe to be true. One of those versions, told by a Tupinikim woman, can be found in the 1999 publication *Os Tupinikim e Guarani contam ...* (The Tupinikim and the Guarani tell ...). The same legend undergoes cultural transformations over time and through contact with different peoples. This particular legend, with the name of Tupi-Guarani root, appeared in Brazil in the eighteenth century, and is still present in books of Brazilian legends.[13]

The most manifest Tupinikim habits are related to body painting, games, crafts, feasts and the practice of agriculture under the influence of the planets. Body painting is one of the traditional forms of Indian art and continues today with marked features and a strong meaning for those who practice it. The use of the dark pigment of the genipap (*genipa americana*) signifies a readiness for celebrations and rituals since the color black is used to denote happiness and peace. In contrast, the use of the pigment from the annatto (*bicha orellana*, *urucu* or *urucum* in Tupi), which is red, denotes a readiness to fight since red signals disagreement and unhappiness. The simultaneous use of the two colors means that something is being negotiated and that there is an openness to dialogue.

Music and dance have long been rooted in the life of the Tupinikim. Natural materials are used to make musical instruments such as rattles which are used for more than one purpose (children's toys, crafts, instruments to mark rhythm in music). The "Congo" is a type of music that originated in interaction with former black slaves. Its intense rhythm is provided by drums. The Tupinikim dance to the Congo; the best known of the dances is the "warrior's dance." Present-day indigenous celebrations are closely associated to Christian feasts, such as the day of Saint Benedict or the *festas juninas*; this reinforces an already considerable Christian influence.[14] One of the most popular children's games consists of making a footpath in the forest. Children divide into two groups: one has the function of marking the path, and the other of discovering it. The path is indicated with gourds that are already known to the second group. The game ends when all the gourds have been found and the path discovered. The game of spinning a top, already known to the Greeks and Romans before Christ,[15] must have been intro-

[13]See (Mugrabi 1999, 67–69). See also http://sitededicas.uol.com.br/folk01.htm.
[14]The *festas juninas* are celebrations of popular saints and rural life derived from the Portuguese Midsummer Day, itself historically related to the pagan celebration of the summer solstice.
[15]See www.construirnoticias.com.br/asp/materia.asp?id=1353.

duced into Brazil by the colonizers and was assimilated as a game by the Indians. In addition to industrial tops, the Tupinikim use ones they make themselves which they adorn with painting typical of their culture.

Tupinikim crafts are among the most appreciated in the region. They are generally made by women and represent an important contribution to the family budget. In the Aracruz municipality there is an association of women who work together to make crafts commercially. Children and men help them by collecting raw materials from the forest. The most commonly produced objects are wristbands, earrings and necklaces, bows and arrows, *samburás*, *tipiti* (kinds of baskets), sieves, small clay pots, baskets, gourds and axes.

Anthropologists such as Ramos (1943), Métraux (1950) and others affirm that the ancestors of the Tupinambá family lived in groups of houses (*ocas*) built on a rectangular piece of land called *ocara*. The houses were rectangular, between $50m^2$ and $200m^2$, and were made of tree trunks set into the ground; these trunks supported transversal beams joined with liana, and the houses had a roof made of palm tree leaves. Other houses, built according to the technique known as *taipa*, had walls of mud and wood. This tradition has not been entirely lost, even though most of the houses today are masonry.

In today's villages one sees, alongside masonry houses, others constructed with materials from the forest, in conformity with Tupinikim tradition. Magalhães considers the following explanation by Yby-Membyra, an inhabitant of the Caieras Velha village, as representative:

> My daughter's house is made of plaster, and the house of the people who've been here longer was like that, with walls made of palm-tree trunks and mud. And the roof, with bundles of nayhá straw. That changed as we got to know other people. I think Indians began to feel ashamed to remain that way next to those persons who live in masonry houses, and wanted also to work in order to have that kind of house. I think it's also because of this that our tradition disappeared. We went on changing our way of living. (Magalhães 2007)

The Tupinikim plaster house is built entirely with natural materials such as earth and trees, according to structural principles that are thousands of years old, and generally with women's help. In addition to allowing group collaboration, the advantage of this kind of construction is that it eliminates the need to buy materials commercialized by the non-Indians. But even this traditional home-building technique has assimilated one element of the white population's culture, namely a whitewash to protect the house from humidity and to fill narrow crevices, thus keeping out insects such as the *Trypanosoma cruzi*, which causes Chagas disease. Today the masonry houses are preferred to the traditional ones, and they are constructed collectively under the guidance of those who already master that building technique.

The Tupinikim cook in the kitchen and next to their houses. Traditionally, food was obtained by hunting, fishing and gathering fruits. The interaction with other cultures and the limits imposed on their territory gradually modified their eating habits, as told to Magalhães by a chief of the Irajá village:

> We were brought up eating fresh-water fish, game, birds, fruits from the forest, swamp shellfish and crab, in addition to cultivated products, such as sugar cane, coffee, manioc, pumpkin, green beans, pigeon peas, and others I now don't remember. We all had some domestic chickens, and those who had pigs gave the other families some lard. For some time now we have vegetable gardens, each family its own, with onion, garlic, scallion. Few people plant tomatoes, because we don't eat tomatoes in our culture. It's not as it used to be. Times have changed. (Magalhães 2007)[16]

The Tupinikim still cultivate maize, some types of beans and manioc, sugar cane, coffee and several types of potatoes (sweet, *cará*, English, *caratinga*). In the family gardens they plant various kinds of vegetables such as lettuce, tomato, watercress, mint, onion, scallion, garlic, cabbage, cilantro and parsley. The habit of consuming these products is more recent and is related to the interaction with the non-Indians. In the villages, the most common fruit trees are the acerola, annatto, pitanga (a red berry), guava, avocado, Brazilian guava (empharaçá), coconut, orange, mango, jack-fruit (*jaca*), genipap, jabuticaba, lime, passion fruit (*maracujá*), banana and papaya (*mamão*). Some of them—the araçá, genipap, jabuticaba, passion fruit, pitanga and anatto—are native Brazilian species.

The Tupinikim eating habits include, in the first meal of the day, coffee and potatoes; for lunch they eat beans, rice, maize or pasta, meat or fish with manioc flour; in the afternoon they eat fruit or have coffee with other industrialized foods such as bread or milk; in the evening, they prepare a meal. Drinking tea is a very common habit; infusions are prepared with native herbs and can have the function of treating or preventing illnesses.

Drinking the fermented *coaba* is an ancestral habit of the Tupinikim. The *coaba* is prepared with *coin*, a sort of wild manioc which is cooked, crushed, and left to ferment for about three days. The drinking ritual takes place on special occasions such as the welcoming of guests and celebrations. Some drink the *coaba* in the shell of the *cuité*,[17] a sort of gourd. The effects of the *coaba* are like those of alcohol and for this reason some Tupinikim object to its consumption.

Some health practices are intimately related to the Tupinikim cultural heritage concerning the medicinal use of plants. An informant from the Pau-Brasil village told Magalhães (2007) that she knows by heart some recipes, such as the one for a syrup made of plants like acerola and pitanga, as well as the succulent

[16] Jonas, Chief of the Irajá village, November 2006.

[17] The *cuité* resembles a coconut, and is used to make the *berimbau*, a musical instrument of African origin.

"saião" (*Kalanchoe brasiliensis*), wiregrass ("pé-de-galinha," *Eleusine indica*), and ironweed ("assa-peixe," *Vernonia polysphaera*), capable of curing even pneumonia. The fat of animals such as capibaras (*Hydrochoerus hydrochaeris*), lizards and nightjars serve to treat bronchitis and inflammations.

One of the pajé's important functions in the village still is to give advice and to prepare medicine. He himself looks for and collects medicinal plants in the forest. For the most common illnesses, most adult members of the group know which plants are useful and how to prepare remedies with them. Prayers, however, are still a means of healing certain conditions. The Pajé of Caieras Velha tells part of his life history to Magalhães:

> My father was a healer and my uncle too. They never taught me any of that. But when I was 12, an adult Indian here in the village came to me and asked me to pray because he was suffering from an unbearable toothache. As soon as he asked me, I shivered with fear, and without knowing anything, I prayed for him. After that I felt relieved because I was certain God would take away that pain, that suffering of his. Then I told my father what had happened. My father told me that he too had the gift and the vision to heal. From that day onwards, I never stopped. I am 91 years-old and until today I pray for pain on the side, toothache, stomach-ache. I pray for any illness, everything I can understand. I don't cure venereal diseases, I don't understand [them]. (Magalhães 2007)[18]

Although, as we see, the pajé cures many illnesses, he does not treat all of them; Alexandre, for example, excluded venereal diseases. For such diseases, the Tupinikim appeal to the medical knowledge of the non-Indians. The existence of health posts in the villages is something recent in their lives. These medical stations offer pre-natal assistance, vaccines, small sutures and emergency help. When the women return to the villages after giving birth, they continue to employ traditional remedies, using plant baths to prevent infections.

We see clearly here how sometimes tradition becomes prominent and combines with the external culture, thus transforming native culture. But the opposite also takes place, as when non-Indians assimilate native cultural habits, thus transforming their own customs and opening up spaces to live together harmoniously.

Over time and through contact with the non-Indians, the Tupinikim also changed their habits of dress. The chief of the Comboios village told Magalhães about the transformation, from the time when they were totally naked, with body paint as their only clothing, to their present use of industrialized clothes:

> When I was a child, both my cousins and I, and all the children of the village, went around naked until we were 11 or 12 years-old. After that age, our parents dressed us as if we had uniforms. Our day-to-day

[18]Pajé Alexandre Cezenando, Caieiras Velha, October 2006.

> clothes in the village were the same as those of our ancestors: tow or cotton bags. All one had to do was to make holes for each sleeve, and the clothing was ready. It was a sort of nightgown. [...] Whoever wanted to personalize his clothing, his gown, painted, primarily with annatto, or drew something, like a bow and arrow, or some other object of our culture, or a bird or plant he liked. The color came from the pulp of crushed fruits that stain, and cannot be eliminated, like that of the annatto. [...] When we were teenagers, my cousins and I used the same bag as if it were a skirt (like a loincloth) and not as a gown. We wore it that way to be able to paint our bodies, our chest and back, so we could feel more adult. I myself experienced that. (Magalhães 2007)[19]

23.4.2 Guarani

Due to their symbiosis with nature, which they value above all, the Guarani prefer to dwell in the forest and avoid open fields. The white man's occupation of lands previously inhabited by native Brazilians has brought about transformations and difficulties in the maintenance of that tradition. In our conversations we noted their concerns about the importance of the space they inhabit so that Indians and non-Indians can live together peacefully and harmoniously.

> The Tupi Indians are organized in a very different way from other peoples, because space must be distributed among them according to the number of families. Families need room for planting, room for hunting. Today we have a very limited space for the Tupinikim and Guarani families. In such a restricted space they are all massed up, which makes peace difficult.[20]

Ideally, all houses should be oriented towards sunrise, like the house of prayers. But that is not always the case. For building, a wood harder than cedar is used. The village homes are generally divided into two parts, one for eating, another for sleeping. The bathroom is outside the house. Some sleep on the floor or on a mat, a net, or even a bed. Those who do not have money to buy a bed make a *girau*, a crude bed made of wooden rods.

There are presently many houses with mud walls and covered with palm tree leaves. Figure 23.3 shows the construction of a house in the Boa Esperança village. It is approximately 4m x 4m, has only one door and one window, and was being constructed for a pajé. The walls are made of bamboo secured with wire (formerly liana was used) and filled in with mud from the earth next to the construction site; it is, however, covered with industrial tiles. Adults and children from the community help each other with the construction (this regime of mutual help is

[19] João Mateus, Cacique of Comboios, September 2006.
[20] Interview with Mauro Luiz Carvalho, Guarani educator, 2007.

Figure 23.3: The former chief Jonas explains how to use raw materials (mud and bamboo) to build a more traditional Indian house, which has a lesser impact on nature. (Photo by Silva, 2008)

called *mutirão*). This shows that they have preserved knowledge inherited from their ancestors, even though they have assimilated the use of industrial materials introduced by the non-Indians. Marcelo Oliveira da Silva indicates one of the reasons for the use of industrial materials:

> Today we no longer find in the forest many natural materials to build houses, as it used to be. If we cut trees, little by little our forests will disappear, and the palm straw as well. (Silva 2003, 117)

Such justification seems partly accurate, given that it is indeed easier to obtain materials manufactured by the non-Indians than to extract and handle materials from nature.

In the Três Palmeiras village one finds many houses with thatched roofs (palm tree leaves). Marcelo Oliveira da Silva, a former Guarani chief and transmitter of Guarani culture, explains how a house was traditionally built:

> It was made of lath-and-plaster, with a hardwood frame. Mud was mashed with the feet and then put on the house frame to make the

> walls. […] The roof was made of coarse hay (*kapi'íguaçú*). The houses were tall, and inside there was always a fire to heat it up and chase away jaguars, snakes, mosqui-toes and insects. All the houses were built facing the rising sun so that the sun's rays would clean the interior. They always have two doors, one at the front and another at the back. (Silva 2003, 177)

Today, Guarani crafts are not only an artistic form of expression, but also a means of subsistence. The Guarani themselves commercialize their creations and many families live almost exclusively from this kind of business. The inspiration for the crafts is very much connected to nature, from the raw materials such as liana, embira (a sort of bast fiber), grains, bird feathers, stones, wood, shells and animal bones to the forms and images of animals, plants and planets. With those materials the Guarani produce different types of objects: bows and arrows, blowguns, baskets, mats, axes, spears, fans and bags.

Basketry is one of the most interesting artistic productions of the Guarani. To understand the meanings inherent in Guarani crafts, knowledge of the culture of that ethnic group is required since the Guarani express their religion, beliefs and myths in their products. For example, the symmetrical motifs on their baskets refer to patterns found on the skin of animals such as the cobra. Other motifs, such as the *kuruxu* (cross), have a religious symbolism. The sculptures of animals, such as the *xivi* (jaguar), which lived in Guarani territory and is part of their legendary heritage, remains present in the crafts; other represented animals include the owl, the caiman and snakes, as well as other birds, fish and animals.

23.5 Education

Education as a means of preserving and ensuring the continuity and survival of minority languages such as Guarani and Tupi is a general concern for all those involved in the education of native Brazilians. Native ethnic groups have had to face the oppression of the cultural, social and economic domination of the non-Indians, who imposed their own language, values, and social norms.

Educational matters must be considered in connection with the need for ethnic groups to live in harmony with nature and with the other populations. One of the major concerns is the struggle for land, which is indispensable for the traditional Guarani and Tupinikim way of life.[21] This constitutes one of the basic differences between Indian and non-Indian education.

As a social institution, the school is not limited to pedagogical functions, but needs to take into account social assumptions and cultural contexts in its educational project. Self-confidence is necessary to execute effectively a curriculum

[21] *Struggle for land* designates the Indians' constant struggle to recover land which, since the 1970s, has been occupied by factories such as that of the giant company Aracruz Celulose.

and other educational initiatives. If that is lacking, then the school rituals will fail due to a lack of commitment of the teachers involved (Damerow 1990, ix).

In thinking about important educational initiatives, we need to pay particular attention to the curriculum and be very aware that it makes no sense to “copy” the non-Indian curriculum. Rather, one must take into account the social and cultural specifics of the ethnic groups, particularly insofar as they differ from those of the non-Indians with respect to language, beliefs, and integration with nature. In addition, since the mother tongue of the ethnic groups is not Portuguese, the curriculum of non-Indian schools must provide a bilingual education. This is not an easy task since it often requires the collaboration of Indian and non-Indian teachers in planning and executing appropriate curricular activities. The study of native languages is therefore another specific of non-Indian schools.

23.5.1 Tupinikim

As noted by the sociologist Florestan Fernandes (1964, 11) the education of the Tupinikim, as an ethnic group of Tupinambá origin, aimed traditionally at integrating the individual in his or her society, emphasizing knowledge about nature in order to ensure their survival. The teaching and learning process was based on imitation and on “learning by doing.” In traditional education, aptitudes and values were transmitted by the rituals of passage between childhood, adolescence and adulthood, different for men and for women. The predominant educational process, however, was informal; the production of knowledge took place in everyday practical circumstances. In a general manner, one can say that cultural transmission took place orally, with the participation of society as a whole. Moral and spiritual education was the pajé’s responsibility.

Currently, although the Tupinikim maintain many of those specific educational orientations, many important transformations happened after the introduction from the 1980s of village schools and formal education. These transformations have to be discussed in relation to the Tupinikim aspiration for an intercultural curriculum. They wish, for example, to include in the school curriculum the teaching of the Tupi language as well as the history of the Tupi.

23.5.2 Guarani

In Guarani society, the learning process is much more intense than the teaching process. As Maria das Graças Cota (2000) shows in her M.A. thesis on indigenous school education, Guarani schooling gives a primordial role to oral transmission and respectful listening. The house of prayers is the Guarani child’s first and most important learning space. Oral education plays a fundamental role among the Guarani, who pursue personal perfection through the improvement of their speech, which is also the vehicle of wisdom and highly valued within the community.

Figure 23.4: Third-grade Guarani children of the Aldeia Boa Esperança. (Photo by Silva, 2008)

In 1993, the Guarani defined the education they want for their people as an “indigenous education,” and not as an “education for Indians.” They proposed the following guidelines:

1. Education ought to be bilingual and alphabetization should take place in Guarani.
2. The school should be different from the official school; the teachers should be Guarani and respect the costumes and traditions of this ethnic group.
3. All decisions about the functioning of the school have to be discussed with the communities.
4. The school should teach the history of the Guarani people and ensure the continuity of Guarani culture.
5. It is important to know the world of the white people in order to avoid being harmed or cheated, to learn how to negotiate, demand rights, and so forth.

6. There should be an exchange of experiences among Guarani schools so as to develop a unified Guarani education.
7. Guarani schools should be officially recognized.

Extending these guidelines, in 1995 the Guarani defined the goals of an indigenous education in the following terms:

> […] the command of the social, economic and cultural autonomy of each people, contextualized within the recovery of historical memory, the reassertion of ethnic identity, the study and valorization of their science as synthesized in their ethnic knowledge, as well as access to information and technical and scientific knowledge produced by the larger society and the other Indian and non-Indian societies. (Cota 2000, 56)

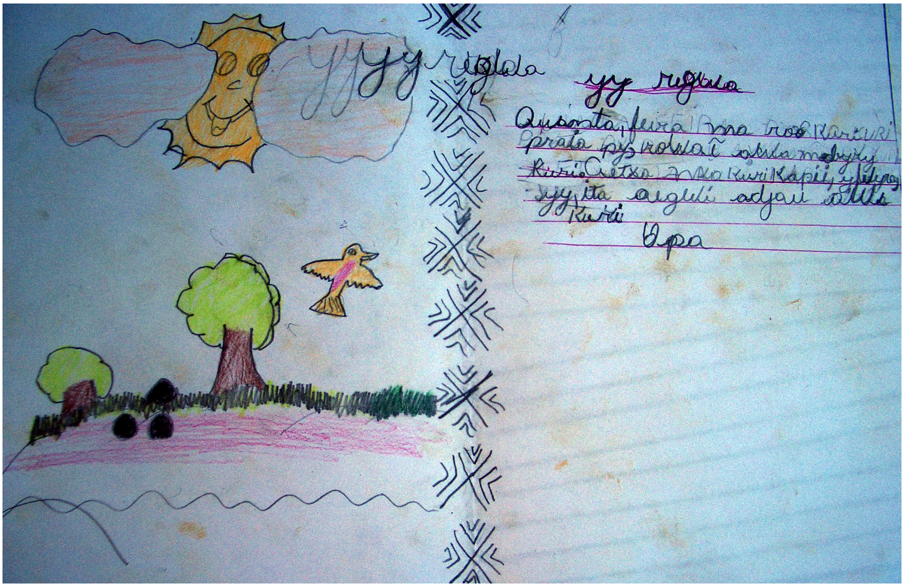

Figure 23.5: From a composition by a third-grade child in Silvio Carvalho Gonçalves' class at the Boa Esperança school.

The text in Figure 23.5 illustrates the existence of bilingualism in the village schools that seek to follow the guidelines and goals defined in the 1990s. In this composition by a third-grade child who is almost bilingual we see two parts: one consists of the illustration of the topic of the text, the other includes a text in Guarani with some Portuguese words. The child already knows how to use the

language of textual narrative, and has produced a coherent text that includes a title, a beginning, a development and an end.
The text reads as follows:

> Talking about water
> On Thursday we went to the beach, it was far for us to get there. I saw grass, trees, water, stone, and also went bathing.
> End

We see the word *quinta-feira* (Thursday) in Portuguese—a choice justified by its absence in Guarani as well as in other native languages not influenced by Christianity. It is also worth noting here that the Guarani's measure of time is different from the non-Indian's. For example, Guarani lacks words for days of the week and has no specific word for "time." There is nevertheless a more general treatment of time, with expressions such as "from time to time" (*pokã*), "a long time ago" (*yma*), "recently" (*ramo*), "a long time" (*are*).

In addition, both Guarani and Tupi lack a word for an abstract concept of space. The drawing of a Guarani child (Figure 23.6) shows a representation of space understood as a place in which she lives (*tekoa*),[22] with an emphasis on nature, which has great significance for her. The *tekoha* has three levels: the physical-geographical, the economic and the symbolic (Ciccarone 2001, 127).

In both the Tupinikim and Guarani contexts, the success of any curricular initiative depends on the training of native teachers and their professional commitment to teaching that includes bilingualism, the history of those ethnic groups and their free access to global knowledge about their own interests. Some steps are being taken in this direction: Indian educators have participated in courses for teaching languages and have obtained professional diplomas and graduate degrees from institutions in Espírito Santo and other states, with financial support from the state. In addition, extension courses are offered in the villages for the orientation, evaluation and implementation of school curricula, with the participation of investigators, including the authors, who are interested in investigating this area.

23.6 Changes in Cultural Practices

Contact between Indians and non-Indians, as well as between the Tupinikim and the Guarani has naturally brought about constant transformations in the cultural practices of those groups—sometimes imposed, sometimes through a process of assimilation or negotiation. These transformations happen both in the long and in the short term in the midst of a broader globalization process which, as Renn (2007, 45) puts it, "does not necessarily mean abandoning traditional knowledge but may well open up new spaces for it."

[22] For the Tupinikim, and especially for the Guarani, the space in which they live has enormous importance; this is where they obtain subsistence from nature, where there is a forest and water to fish and hunt.

Figure 23.6: Drawing by a Guarani third-grade child from the Boa Esperança school.

Traditionally, the Tupinikim and Guarani were hunters and gatherers; through the practice of hunting and gathering, they developed the knowledge necessary for their survival. Thus, they constructed and used various hunting tools, such as bows and arrows, spears, as well as traps for fish and game. In addition, they elaborated a special technique for spatial orientation when following animal and human trails. Today, however, that knowledge is hardly used and is practiced by only a few persons in the community, generally leaders or the elderly. The contact with the non-Indian has brought into the ethnic communities knowledge as well as instrumental and technological innovations that have replaced traditional usages. Eating habits are representative of such changes: for centuries, Tupinikim and Guarani nourished themselves by fishing, hunting and gathering, and only later agriculture. The use of industrialized food, however, has been rapidly adopted through contact with non-Indians, even though the older hunting, fishing and gathering practices have not been completely abandoned.

It is difficult to evaluate the impact of such changes; our observations are consistent with Jared Diamond's remark that: "In the case of technological innovations and political institutions as well, most societies acquire much more from others' societies than they invent themselves" (Diamond 1998, 406).

The fact that the Tupinikim and Guarani share territory with non-Indians facilitates exchanges and the spread of knowledge. Though referring to a larger context, the following observation by Diamond (1998, 406) is applicable to this situation too: "diffusion and migration within a continent contribute importantly to the development of societies, which tend in the long run to share each other's developments (insofar as environments permit)."

Native agriculture began to be transformed at the very beginning of the Spanish and Portuguese conquest. The Spanish and Portuguese not only introduced plants unknown to the Americas, but also took to the old world native-American plants.

> These included [crops] both those familiar to European farmers, such as wheat, barley, oats, and many temperate vegetables and fruits catering to European food tastes, as well as tropical crops from Africa and Asia, such as bananas and plantains, sugar cane, and rice. At the same time many American crops were carried to the Old World—the most important being maize, potatoes, manioc, beans, and squash. (Schwerin 2008, 56)

The Tupi-Guarani system for preparing fields for planting is called *coivara*.[23] It includes first cutting down trees and thickets with stone axes, followed by burning part of the material. Trunks, as well as the larger and stronger branches, are used for construction; ash is used as fertilizer. Women participated in the *coivara* and used a wooden hoe to move the earth and plant. These tools have now been replaced by others, industrially manufactured and of non-Indian origin. The *coivara* system nevertheless persists. The fields used to be common, but have gradually become the responsibility of each family and are located close to their homes. One of the causes of these changes might be the limitation of space in the village available to the non-Indians, which prevents nomadic agriculture.

An interesting example of the transformation of cultural practices concerns the preparation and use of salt in food. Salt was an important substance, of alimentary, economic and medical (anti-parasitic) significance in the ancient Eurasian civilizations (including Europe), the Far East, Africa and pre-Columbian America (Adshead 2008, 1912). Salt exists naturally in two forms: as a rock deposit, or as brine from seas, lakes, saline earth and local plants. There are two ancient techniques (developed around 500 BCE in China) for obtaining salt. One consists of boiling down brine, the other of letting it evaporate naturally through the action of sun or wind. The Chinese called the first one *chien*, the second *shai*. The former, considered older, seems to have inspired the latter. Both were subject to careful processing, since the final product could be harmful to health. The reason,

[23] According to the *Léxico Gurani* (Dooley 2006), *coivara* means "to clear land" or "to burn in order to clear land."

according to Samuel Adshead (2008) is that "the *sodium chloride* would be contaminated by the calcium and magnesium compounds contained in most brines and especially in sea water."

The production and consumption of salt in pre-Columbian America was very limited before the arrival of the Europeans. In Brazil specifically, there are very few known instances of an ancient production of salt. Ramos (1943, 103–104) explains that the Tupinambás obtained salt by the evaporation of sea water from ditches dug in the sand on the beach, and that they mashed it with pepper for alimentary use. The traveler Karl von den Steinen tells that in his second Brazilian trip in 1887–1888, he found in the village of Nafuquá in the state of Mato Grosso, salt extract from plants:

> In many houses we found people busy preparing the salt. They burn takoara and aguape, foliage plants from stagnant water, leach the ashes out and from the filtrate obtain a salty residue. Reddish earth resembling potash is also used directly and often.[24]

Today, the Tupinikim use the same industrialized salt as the non-Indians. Nevertheless, old people from the Pau Brasil village attest to the fact that ancient techniques akin to the Chinese *chien* were known and used. During a conversation about food, an old Indian woman told us:

> My mother made salt. She brought sea water and she boiled it until the water had evaporated. Then there was salt.[25]

Those techniques were gradually abandoned due to the ease of procuring industrialized salt.

Among the Guarani, the habit of using salt with food was uncommon. This changed through contact with the non-Indians. In turn, the transformation of Indian practices led to other views and techniques for the production of food, the use of manufactured products and new habits. Such transformations were reinforced by the limits imposed on the demarcation of land, which had an environmental impact and restricted access to certain plants, animals and minerals.

The Guarani have a good knowledge of nature in general, and specifically of plants, which they use not only as food (including sacred foodstuffs) and medicine, but also as raw material for buildings, weapons, clothes, musical instruments and various kinds of tools. In addition, a plant is smoked in a spiritual ritual.

Plant substances for coloring have been known since primitive times and are still in use. For example, annatto (*Bicha Orellana*, "*urucum*") was known before the arrival of Europeans. It was abundant on Brazilian territory and used mainly

[24] The original text reads "In mehreren Häusern fanden wir die Leute mit der Zubereitung des Salzes beschäftigt. Sie verbrennen Takoara und Aguapé, die Blattpflanze stiller Gewässer, laugen die Asche aus und erhalten aus dem Filtrat einen salzigen Rückstand. Vielfach wird auch rötliche, wie eine Salzasche aussehende Erde unmittelbar verwendet" (von den Steinen 1897, 123).

[25] Dona Santa, 8 October 2008, Aldeia Pau Brasil.

for body paint. The use of plants also underwent several changes. One important example concerns the techniques for extracting vegetable and mineral pigments, which are presently known and practiced by only a few Indians. Natural colors have been replaced by industrial products, such as anilines, which are now employed to dye the vegetable fibers used for basket-weaving, or the whitewash used to paint houses.

How were traditional dyes obtained? The genipap, a large tree whose wood is very versatile, has green fruit similar to large oranges, but with thinner skin that turns a brownish color when ripe. From the green fruit a clear substance is extracted, which turns black after a few hours. This is used for body paint and to dye fibers such as the embira—in Guarani *webépi*, a word that is also used to name the liana (*imbé*). This liana is dyed in three colors: brown, red and black. The body paint that was used for protection purposes, as well as for ceremonies and in war, is no longer frequently applied due chiefly to the habit of wearing industrially manufactured clothes.

A dye is also extracted from the cedar-tree (*yari* or *yãri* in Guarani), which can be found throughout tropical America (Figure 23.7). Its wood is prized for its color, which resembles mahogany, and for its various usages. It yields a perfumed oil and tanning substances can be extracted from its bark. Since tannin is soluble in water, an infusion can be prepared from it. Hence the statement of Guarani chief Jonas:

> From an infusion of cedar-tree bark that is boiled in water for about forty minutes, one obtains a brown or coffee-colored dye.

From a porous pink-purplish stone (*itarã* in Guarani), abundant in Guarani territory, one can make a powder which, mixed with water, gives a purple dye.

The *embaúba* (*ãba'y* in Guarani, *trumpet tree* in English), a tree with large leaves belonging to the genus Cecropia, may reach fifteen meters in height. From the bark a brown dye can be produced. The flowers, buds and bark of the stems are used for the treatment of bronchitis, coughing, erysipelas, diabetes and diarrhea. The juice of the roots and leaves has a cardiotonic and diuretic effect. The Guarani educator Aciara Carvalho Marinho explains:

> The leaves of this plant can be used to treat stomach-ache and blood in the faeces.

The leaves of a tree known in Guarani as *ywyra pytã*, or "red tree," are of considerable dimensions (about forty centimeters wide). When steeped in water they produce a reddish-brown liquid which, after drying, produces a red dye, as demonstrated by former chief Jonas in Figure 23.8. The dye can also be obtained by boiling the leaves in water.

Most of the information reported here about dyes was orally communicated by the Indian leader Jonas (Tupã Kwaray in Guarani), who claims to have learned

Figure 23.7: Former chief Jonas harvesting cedar-tree bark, Aldeia Boa Esperança. (Photo by Silva, 2008)

Figure 23.8: Process for obtaining dye from the leaves of the embaúba tree. (Photos by Silva, 2008)

these techniques from his mother and grandmother. When asked about the disappearance of these techniques, he replied that "due to the exploitation by the White, who ruin the aboriginal forest, it became difficult to find the plants, so anilines were used as an alternative." The plants we now see in the village were planted with the goal of preserving or protecting them. Nevertheless, they are still too scant to be used for extraction. Jonas, who now works mainly making crafts, uses hardly any natural dyes, but rather industrial dyes and methods imported by the non-Indians. According to him, he makes crafts because his parents made them, and "if parents make, then the children will make too."

The abandonment of techniques for preparing and using natural dyes illustrates the impact of the dominant culture on indigenous culture. Contact with the White, the rarity of raw materials, and the technical ease of dyeing with industrialized and ready-to-use products are reasons why the Guarani gradually relinquished their traditional methods. The new dyeing technologies, as well as other techniques that were assimilated by the Indians, demonstrate not only the technological superiority of the non-Indians, but also the fact that aboriginal peoples accepted a technology that agreed with their cultural values as well as with their interests. As Diamond (1998, 252) notes, on every continent "certain native societies have proved very receptive, adopted foreign ways and technology selectively, and integrated them successfully into their own society."

Social organization also underwent major changes as a consequence of contact between different groups. Transformations in the social and political relations have been both internal, affecting the community, and external. Among the internal ones, we may mention the distribution of activities between men and women, marriage, education, religious practices and health care. Among the external ones are occupational possibilities, professional training and participation in political life, primarily in defense of the ethnic community's principles and interests.

Formerly the Tupinikim were associated in clans with a main chief (*murubixaba*) and a council of older and more experienced men of which the *pajé* (medicine-man) was one of the most important members. The social status of men and women was well differentiated; the women had to work for the men in domestic and agricultural activities.

The Tupinikim used to practice polygamy (Ramos 1943, 133). Although they still live together in villages, today's Tupinikim in contrast are no longer polygamous and the women are no longer responsible for supporting the family. Contact with non-Indians influenced the Indian man to take on responsibility for the economic support of the family. Some of the men and women now hold paid jobs outside the village. Nowadays, the village leaders have taken on the role of negotiating and defending the political and economic interests of the community, for example, in the attempts at recovering land occupied and exploited by companies such as Aracruz Celulose.

In the area of education, changes began with the imposed establishment of schools in the villages, which made the teacher responsible for the formal education of children. This task was formerly assumed by the most experienced members of the community in such a way that they prepared children for life and transmitted the group's values and cultural heritage.

In the case of the Guarani, the transformations also include the search for paid activities. Crafts, which were originally intended for internal consumption, became a source of income for the families. As for family structure and economic relations, we may quote Schaden who explains that:

> The extended family, including the couple, the married daughters, the sons-in-law and the following generation, constituted a unit of production and consumption. Its breakup perhaps began already under Jesuit influence.[26]

In the Guarani villages investigated, we observed such fragmentation of the family, as well as the focus of each family on cultivating food in its own field. Education suffered the same type of transformations it underwent with the introduction of village schools among the Tupinikim.

In the inevitable process of transformations of practices, we can observe instances of different techniques using natural materials, which are known to indigenous peoples and employed by them, but which are forgotten if not transmitted

[26] Original text reads "[...] a família grande—compreendendo o casal, as filhas casadas, os genros e a geração seguinte – constituía a unidade de produção e consumo. A sua fragmentação talvez se tenha iniciado já com a influência jesuítica" (Schaden 1962, 80).

to the younger generations. Such transmission depends nowadays on school education, which is in turn directly influenced by official curricular orientations and government policy. In general, in several social and political contexts the belief persists that in order to pay the historical debt it is enough to simply provide indigenous peoples with a territory where they can live well. Nevertheless, closer contact with indigenous ethnic groups makes it possible to learn more about their interesting local knowledge, their needs and how globalization affects their way of living and thinking. Their most important legacy for non-Indians is undoubtedly their love of nature as a condition of human survival. Thus, multicultural initiatives in educational, social and political fields should be linked to a reflection about the defense of the environment and the knowledge that all people have accumulated over the course of history.

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PART 4: The Globalization of Modern Science

Chapter 24
Survey: The Globalization of Modern Science

Jürgen Renn and Malcolm D. Hyman

24.1 A New Stage in the Globalization of Knowledge

Science may take on completely different forms in various cultural and historical contexts, but all of these forms of the human acquisition of knowledge share a general nature that lies in their exploration of the potential for innovation embodied in a given material culture.[1] This exploration, focusing on means rather than ends, occurs in a certain autonomy from the specific applications also given with this culture, through its tradition and concentrating on certain goals. Against the background of such a historical definition of science, the remarkable dual character it possesses, its durability and its fragility, becomes more understandable.[2]

The staying power of science and its relative stability are based on its roots in technology with which humanity reproduces its social systems. By contrast, science's lack of endurance and relative fragility lie in its dependency on the motivations prevailing in any given society. This fragility has been reduced more and more in recent centuries as science has gone from a voluntary occupation of small groups of elites to becoming a decisive element of global technology. However, this has made the remaining element of the fragility of science as a social enterprise particularly significant, because the very survival of humanity is determined to an increasing degree not only by the growth of science, but also by the direction and the conscious shaping of scientific progress.

Since the early modern period, the range of science has expanded dramatically, not so much because an alleged scientific method was exported to new domains of experience, but because ever new objects came into contact with the developing network of scientific knowledge and due to the intrinsic, cognitive dynamics of this network. Thus, newly discovered specimens from exploratory voyages, new technological devices, or social and behavioral phenomena that acquired practical relevance, such as population statistics, could constitute challenging objects for the existing scientific framework that eventually acquired global relevance.[3]

[1] See (Damerow and Lefèvre 1981; Damerow 1996; Damerow and Lefèvre 1998).
[2] For the following, see (Renn 2003).
[3] For the notion of challenging object, see (Renn 2001; Büttner et al. 2004; Bertoloni Meli 2006; Büttner 2008; Valleriani 2010). For the role of exploratory voyages, see (Montesinos Sirera and Renn 2003). For the role of population statistics, see, for example, the Census of India which has been conducted since 1871 (Bayly 1999) and also (Gigerenzer et al. 1991).

Knowledge is globalized when it is in principle globally available and accessible. The globalization of knowledge today has reached a new stage: it has transformed the economy of knowledge radically, in ways that are comparable to the transformation in recent years of a monetary economy to a system in which local and global developments are coupled by almost instantaneous interactions. New potentials for the globalization of knowledge have emerged, such as the global system of science and the World Wide Web, offering immediate worldwide access to the knowledge produced within this system. Due to the increased mobility of people and things, research hubs and the human resources of science have become global assets. The migration of scientific knowledge is no longer characterized by the trajectories of individuals or by the dynamics of fellow traveling, but rather by global social patterns.[4]

Scientific knowledge is involved in global economic processes; it is embedded in global infrastructures and regulatory regimes and is part of global cultural products. Its relevance for political, economic and social systems is indicated by the fact that its mere existence may lead to global reactions in these systems, such as value changes in shares, or the occurrence of migrations, summits or even wars. The coupling of the globalization of science to economic globalization has led to a double economy of knowledge: commercial and open. Science itself has undergone massive expansion, alongside an increasing specialization and fragmentation of knowledge. But with the expansion of science new opportunities for knowledge integration and unification also emerged, as well as new perspectives from which knowledge can be judged and evaluated. The globalization of science has led to a self-organizing global distribution of intellectual labor, similar to but different from the global market, in which national institutional structures and epistemic traditions are losing autonomy.

First, we recapitulate the historical emergence of disciplinary science and its crisis in the age of classical science, that is, between the early modern period and the late nineteenth century, emphasizing the integration processes of scientific knowledge and the role of reflective thinking in these processes. Then we turn to the disintegration of knowledge and the globalization of science in the twentieth century, the age of the great wars. We conceptualize the globalization of modern science in terms of intrinsic and extrinsic processes and analyze the transformation of science as a result of its globalization. This discussion raises, in particular, the question of the autonomy of scientific knowledge with regard to its societal constraints. Turning to modes of reflection on globalized science in the age of liberalization, we observe that certain normative ideas about science, here described as the "classical image of science," have become obsolete in scientific practice but are still relevant for the interaction between science and society, limiting the potential of science to address global challenges.

These global challenges are then formulated as the emergence of "socioepistemic complexes," understood as large-scale societal structures, typically of global

[4]See chapter 9.

extent, enhancing the dependence of human society on the production of scientific knowledge. While social studies typically attempt to characterize the morphology of these complexes, they are here considered from the perspective of historical epistemology with regard to their role for human survival. The profound impact on the earth system of human interventions has been described by a geological metaphor referring to the current epoch as the "anthropocene" (Crutzen and Stoermer 2000; Costanza et al. 2007; Schwägerl 2010), thus proposing an image of knowledge adequate to the age of modern globalization. Here we rather insist on the evolutionary character of the development that has led to this stage, and in particular on the irrevocable role of scientific knowledge for its sustainability. Finally, a set of examples will be considered, illustrating the different forms in which socioepistemic evolution currently presents itself.

Evidently, globalization processes in science differ from discipline to discipline. While global big science takes place in cost- and labor-intensive research fields in the natural sciences and partly in the life sciences, the globalization of behavioral and social sciences are a result of the empirical turn and the confluence of national traditions. The globalization of knowledge is clearly not a one-way process of intended transmission, as the previous Parts have shown for other time periods. Also in modern science, knowledge becomes global both by processes of localization and delocalization. Knowledge is always bound to local conditions of its reproduction, and the problem of encounters between different knowledge systems embedded in different local conditions is a persistent feature of historical development. In a word, globalization is path dependent. Yet a convergence of various globalization processes may occur, in particular when they are coupled to the emergent challenges for human survival.

24.2 The Disciplinary Integration and Spread of Knowledge in the Age of Classical Science and European Imperialism

Ever since modern science reached maturity, that is, after the early modern period, its knowledge systems have been organized in terms of disciplinary structures.[5] These structures comprise theoretical frameworks and a material culture, as well as institutional settings that have turned out to be surprisingly stable and surprisingly mobile. In fact, the globalization of modern science has largely taken place in terms of a transfer of these knowledge systems. Everywhere in the world, universities have been set up and organized around these knowledge systems, with departments for mathematics, physics, chemistry, biology, and so on, and with comparable curricula.[6] This astonishing uniformity is not just a remnant of imperialism and colonialism; it is not primarily due to a dominating intellectual culture of rationality, nor is it simply a functionalist response of societies to deal with intellectual challenges to which there would not be any alternative.

[5] See (Stichweh 1984; Damerow and Lefèvre 1998).
[6] See chapters 18 and 25, and the discussion in (Osterhammel 2009, 1132–1139).

Rather, the existing scientific disciplines represent historically contingent systems of knowledge, resulting from a long history of knowledge integration and reorganization that has made it possible to condense a broad range of experiences in terms of a few core concepts, models, methods, technologies and institutional setups for each field. It is this condensation of knowledge that accounts for the high degree of autonomy of the disciplines with regard to specific local contexts, giving modern science the appearance of universal validity. This condensation makes it, at the same time, difficult to realize the implicit context-dependence of modern science, which is inherited from its contingent history but obliterated in its trajectory of "recursive blindness," that is, of ways in which prior knowledge becomes opaque with the accretion of new knowledge. This blindness accounts, at the same time, for the intrinsic difficulty of modern science and its protagonists to reflect on the contexts of its implementation.

The role of contingency in knowledge integration becomes evident, however, when looking at the origin of core concepts of science. In the following, we argue these concepts are not the presupposition of knowledge integration but its results and that integration is never definitive but rather may give way to disintegration. Hence, the core concepts are themselves subject to further transformations, as well as are the disciplines organized around them.

In the core disciplines of the natural sciences as they emerged between the early modern period and the late nineteenth century, a handful of concepts structured a vast array of scientific knowledge. The concepts of space, time, force, motion, matter and a few others played this role for classical Newtonian mechanics; together with the concepts of energy, entropy, field and charge, they also played this role in developed classical physics.[7] The concept of chemical compounds played a similarly foundational role for chemistry (Klein 1994). The concepts of species, gene, selection, variation and adaptation structured classical evolutionary biology,[8] and the concepts of cell, bacterium, pure culture and infection classical microbiology.[9] Second-order concepts, such as 'fact,' 'evidence,' 'proof' and 'objectivity' denote shared control structures and practices aiming at institutionalizing and internalizing the reflective character of scientific thinking, establishing its supposed universality in specific, historically contingent ways.[10]

In retrospect, such core groups of concepts may appear to constitute the starting point for gaining scientific knowledge in their respective fields. A closer historical examination shows, however, that such core groups of concepts usually achieved their privileged position in the organization of knowledge only after a long process of knowledge integration, in a material, social and cognitive sense. The emergence of a core group of foundational concepts in the course of such integration processes can thus be understood as a restructuring of the cognitive

[7] See (Renn 2007a).
[8] See (Beurton et al. 2000; Lefèvre 2009).
[9] See the discussion in (Müller-Wille 2004).
[10] See, for instance (Daston and Galison 2007).

organization of knowledge that was previously acquired under rather contingent circumstances.

Historically, the formulation of the laws of classical physics, for instance, was shaped by the central role of specific challenging objects of early modern technology, such as artillery or the pendulum.[11] They were seen in connection with that other great challenging object of the early modern world, the motion of the planets, leading to Newton's formulation of a concept of force applicable to both. Reflective thinking played an important, but not always appreciated, role in such restructuring processes. This role is evident, for instance, in the attempts by Descartes, Newton and Leibniz to achieve a philosophical integration of physics and mechanics, which largely shaped the emergence of classical physics.[12]

It is particularly evident in historical attempts to provide an explicit philosophical synthesis of scientific knowledge. An outstanding example of the role of reflective thinking in philosophical integrations is the long-lasting influence of Kant's natural philosophy on the self-understanding of classical science.[13] It emerged from the reflective integration of key concepts of early modern science and remained the dominant philosophical background of the increasingly specialized sciences, whatever changes of systems in philosophy took place (Köhnke 1986).

It was a common feature of knowledge integration in the period of classical science, between the early modern period and the late nineteenth century, that foundational, first-order concepts of a particular body of knowledge, such as the concept of force, were exploited to achieve such a philosophical integration. Thus, the mechanistic worldview, dominating physics from the seventeenth to the nineteenth century, could be formulated in terms of matter, motion and force (Dijksterhuis 1983). But the later revolutions of modern science, such as quantum theory or Einstein's theory of relativity, made it evident that such concepts do not correspond to a universal structure of the world or of its understanding by humans.[14] Rather, it became clear that key concepts of classical physics including space, time, matter and force actually correspond to fundamentally anthropomorphic mental models that were no longer adequate when scientific experiences were significantly extended to include such phenomena as the evolution of an expanding universe or the splitting of an atom. From a historical and philosophical perspective, the anthropomorphic origin of some of these concepts had always been more or less discernible (Mach 1989), while it was virtually forgotten in the textbook formulations of the seemingly universal laws of classical physics.

By the nineteenth century a differentiated distribution of labor had been established between different institutions of research and education. Also, institutionalized science policy had emerged as a new form of reflection on the rapid development and increasing significance of science organization. Science began to

[11] See (Renn 2001; Lefèvre et al. 2003).
[12] See, for example, (Damerow et al. 2004; Freudenthal 1986).
[13] See (Friedman 1992; Lefèvre 2000; Zammito 2002).
[14] See (Renn 2007b), in particular (Renn and Sauer 2007).

have a major, global impact on human life. New means of generating energy such as the steam engine, new means of communication such as the telegraph, or new measures against widespread diseases such as antibiotics and vaccination, would have been inconceivable without the close association between science, technology and social and economic development. In addition to the consolidation and specification of the academic disciplines, the era of the Industrial Revolution also saw a further differentiation of modes to produce scientific knowledge, in particular between research more or less closely associated with technological and industrial applications.[15]

Science-based industries, such as the chemical, the electrical and the pharmaceutical industries, came into being, turning the market, alongside the military, into a major driving force of innovation in science as well.[16] As a consequence, the economy of resources and the economy of knowledge became ever more closely intertwined, thus preparing the ground, from the end of the nineteenth century, for the Second Industrial Revolution, associated first with this rise of science-based industries and later with the global spread of electronic appliances.[17] Science thus became part of a self-accelerating process in which science-based technical and commodified applications, such as photography, telecommunication and later computer storage, are being employed as tools for further exploration. The conditions for scaling up the development of science were accordingly themselves a consequence of science and its technological implementation, including the emergence of modern transportation and communication technologies.

Scientific knowledge spread through its increased economic, military and political significance, including the creation of educational institutions with an ever greater penetration of society and extended international collaborations, by way of its technological implementations, including the dissemination of black box instrumentation, but also with imperialism and colonialism. The turn from the nineteenth to the twentieth century was characterized by a growing scientific rivalry triggered by the emergence of Germany and the United States as political-economic powers that challenged British imperialistic hegemony. During this period, the British exported administrative knowledge, practices and institutions as well as Western ideologies such as nationalism; at the same time, local knowledge flowed from colonies to the Western centers. The international regime was based on the theory of free trade and legitimized by it.[18] Because of its association with practical, for instance military, applications, science in this period also began to

[15]See (Damerow and Lefèvre 1998; Carrier 2008; Klein 2012).

[16]See (Baracca et al. 1979; Hughes 1983). For the chemical industry, see the classic study (Haber 1958). For a more recent approach, see (Aftalion 1991). For the pharmaceutical industry, see (Friedrich and Müller-Jahncke 2005).

[17]See the definitions given by Carlo Schmid (1956) and Joel Mokyr (1998). Schmid defines the economic changes after World War II as the Second Industrial Revolution, while according to Mokyr, it occurred between the last third of the nineteenth century and the beginning of World War I.

[18]See (Gallagher and Robindon 1953; Semmel 1970).

serve as an incentive for cultural assimilation and for the creation of social systems capable of absorbing it. Vice versa, new disciplines such as ethnology and anthropology emerged, integrating knowledge acquired during colonization into the system of science.[19]

24.3 The Disintegration of Knowledge and the Globalization of Science in the Age of the Great Wars

During the First World War, science became a major military and economic factor, enhancing the tension between its international character and its involvement in national policies.[20] The interwar period between 1918 and 1939 was characterized, on the one hand, by the disintegration of international cooperation within the West and the emergence of nationalistic policies emphasizing isolationism and economic autarchy and, on the other hand, by attempts to create new international organizations such as the League of Nations, the Red Cross and the Socialist International. At the same time, this period was a transition from British to US economic and political dominance, and from the international regime of free trade to that of an "embedded liberalism," which included protectionist elements. Nationalistic tendencies in terms of economic regime affected the flow of knowledge and the possibilities of scientific cooperation, both among Western countries and between them and peripheral and semi-peripheral countries.

The foundational concepts which had emerged from the first ground-breaking periods of knowledge integration, such as those of space, time, matter and force in the case of classical physics, proved to be extremely stable in the face of an enormous growth of knowledge in the course of the further development of science. In fact, they even were considered to have a priori status, not subject to any changes by the accumulation of knowledge. Nevertheless, core scientific disciplines witnessed fundamental changes of precisely this core group of foundational concepts in the period between the mid-nineteenth and the mid-twentieth century. These fundamental changes were preceded by more or less extended periods of knowledge disintegration, in which the established cognitive organization of knowledge became problematic. Paradoxically, it appears that the essential mechanisms at work in these periods of destabilization were of the same nature as those which functioned in the original processes of knowledge integration.

When classical physics reached a crisis at the turn from the nineteenth to the twentieth century, Kantianism saw a spectacular revival, not only in the modified form of Neo-Kantianism and conventionalism, but also in the emergence of a new type of philosophical integration, often labeled as "scientific philosophy." It was a last attempt to achieve an overarching scientific worldview with the help of

[19]See (Harris 1968; Asad 1973; Kuklick 1991). The close relationship between colonialism and the emerging field of anthropology (ethnology) is also discernable during the eighteenth century. For the emergence of ethnography during the exploration and colonization of eighteenth-century Russia, see (Vermeulen 2008, 2012).

[20]See (Ash 1996; Berg et al. 2009).

philosophical methods that entered into the semantics of scientific concepts. This attempt failed, however, for a number of reasons, both intrinsic and extrinsic, and gave way to the so-called "linguistic" turn of philosophy.[21] The novel feature of philosophical integrations after the linguistic turn was that they were based on a reflection on the syntactic structures of the representation of scientific knowledge by language. As a consequence, the basic concepts of this integration no longer had any direct relation to first-order concepts, so that the integration became content-independent and formal.

Since the beginning of the twentieth century, reflection on science tends to be separated into four branches: a philosophical-normative branch, a historical-descriptive branch, a political-pragmatic branch and the reflection taking place within science itself. The result was a split of rationality, largely separating science from a reflection referring to its contents as well as to its contexts and its societal conditions.[22] However, such a separation could obviously not be absolute and was challenged by alternative interpretations of science as well as by often ideologically motivated attempts at its alternative systematization and organization.[23]

The very possibility of scientific progress continued, in any case, to depend on processes of knowledge integration and disintegration mediated by reflection. Such processes of integration and disintegration within and between disciplines always remained closely connected with first-order concepts and their reflection in view of the acquisition of new knowledge. An outstanding example is the disintegration of classical physics around the turn of the century and the subsequent partial reintegration into global theories such as relativity and quantum physics, emerging as a consequence of probing deeper into the microstructure of matter and of exploring the physical constitution of the universe, but also in the sequel of new technical developments. The emergence of these theories can be understood as resulting from a reflective reorganization of existing and newly acquired knowledge triggered by borderline problems within the wider field of physics, mathematics, astronomy and chemistry.

The disciplinary specialization of science in the nineteenth century had generated these borderline problems located at the intersection of knowledge systems organized into different disciplines or subdisciplines (Renn 2007a). Through these borderline problems, distinct conceptual frameworks came into contact and sometimes into conflict with each other, triggering their integration and reorganization. Quantum physics, for example, emerged at the beginning of the twentieth century because the new technology of electric illumination and its widespread implementation required measures of control and standardization on the part of state-supported research institutions. These measures triggered research on a bor-

[21] See, for example, (Carnap 1934; Wittgenstein 1961; Hintikka and Hintikka 1986; Awoday and Carus 2007). For further discussion, see (Engler and Renn 2012).
[22] For a global history of rationality in which the split of rationality from other human faculties plays a central role, see (Vietta 2012).
[23] For alternative interpretations, see (Rheinberger 1997; Freudenthal and McLaughlin 2009). For Soviet Marxism as an example of an alternative systematization, see (Graham 1993).

derline problem between electromagnetism and heat theory, the so-called black body problem, which in turn gave rise to questioning the fundamental concepts of classical physics. New concepts, such as the quantization of energy, were formulated in response to this crisis. These concepts turned out to be relevant for a wider domain of physics and chemistry as well, expanding the range of the crisis and eventually leading to a completely new understanding of the microscopic structure of matter and radiation (Büttner et al. 2003).

Such processes of reconceptualization typically involved rearrangements on all levels, institutional as well as cognitive, including the refocusing of traditional research activities induced by the discovery of a new common thread, connecting hitherto separate problems. Also typical was the interaction of heuristic programs, which aim at knowledge integration, and traditional structures of knowledge, be they cognitive or social, which are disintegrating. The heuristic programs were comparable to the philosophical programs of an earlier period (mentioned above), although they were now usually formulated from an inner-scientific perspective (which, of course, does not exclude influences from philosophy), and could even take the form of science policy directed at regulating integration and disintegration process of knowledge by institutional organization. Due to the recursive blindness of the sciences and the split of rationality, the intellectual resources offered by prior historical experiences remained, however, often untapped.

Science in the twentieth century was characterized by an acceleration of scientific activity, by increasing specialization and professionalization, as well as by an ensuing fragmentation of knowledge, by a growing commercialization and militarization of knowledge and by the emergence of Big Science.[24] Big Science is the pursuit of science on an industrial scale, with massive investments in equipment and personnel, with an elaborate distribution of labor, and governed by management processes that may involve strong political, economic and military interests. While the emergence of quantum physics in the first quarter of the twentieth century still happened in a rather haphazard fashion that may be described as "big science in an unorganized way," Big Science in the proper sense emerged in the context of the Manhattan Project to produce the atomic bomb during World War II.[25]

More generally, during World War II, science was massively taken into the service of military, economic and political operations, including for singular crimes against humanity as the Holocaust.[26] This happened, however not exclusively and perhaps not even predominantly in terms of the top-down mobilization of its resources by states, but rather by a self-mobilization of science in response to new funding and career opportunities. On the whole, science turned out to

[24] For diverse perspectives on this issue, see (Price 1963; Weber 1965; Husserl and Ströker 1977; Forman 1987; Carrier 2008).

[25] See (Herken 1980; Rhodes 1986; Hughes 2002; Kelly 2007). See also (Garwin and Charpak 2002) and chapter 27 in this volume.

[26] See (Walker 1989; Trischler 2000, 2001; Maier 2002; Weindling 2004; Schmaltz 2005; Maier 2007).

be incapable of coping with the ethical challenges posed by the transformation of its scaled-up economic, political and military implications into criminal abuse. The increased involvement of science in societal issues was, due to the split of its reflexivity into contemplative and pragmatic branches, not balanced by an institutional and intellectual self-organization and self-awareness of science that could have strengthened its autonomy and acted as a counterforce against its instrumentalization.

The period after World War II up to the 1970s was characterized by a combination of international cooperation and world governance on the one hand, and strong statehood on the other. The international regime was such that it allowed for flexibility in the ways states and governments could respond to local challenges without breaching what was conceived legitimate state action. The Cold War, of course, was a decisive factor that shaped the global arena as well as the possible forms of statehood. This international arrangement brought about new modes of knowledge production at national and international levels. The model of Big Science also spread into the non-military domain, while the strong ties between science and the military created during World War II were reinforced in the context of the Cold War.[27]

The launch of the first artificial satellite "Sputnik 1" by the Soviet Union in 1957 led to massive investments into science and education by the Western nations to catch up with the technological advance represented by this achievement. In the United States, federal research and development budget and government funds for universities increased substantially. With the set-up of the President's Science Advisory Committee and the Presidential Science Advisor, focusing on the space program and on strategic weapons, scientists moved closer to government (Geiger 1997). Military research and the space program generated spin-off technologies, such as the microchip, and new materials. Political boundary conditions and the market imposed strong external constraints on the self-organization of science, also acting as a selective force on its intellectual development.[28]

Yet the network of scientific knowledge continued to unfold its own, unpredictable dynamics, which can never be completely controlled by external forces. Even in the presence of strong outside influences, the development of science remains a largely self-organizing process—not least because of its global character—that may or may not be optimized by a society for its own purposes. It is this process that, at the same time, exposes a society to a feedback loop of reflection about itself, making it necessary to confront some of its basic tenets, for instance about economy, justice, health or environment, with the cognitive potentials inherent in science.

[27] See (Galison and Hevly 1992; Trischler 2000; Krige 2006a).

[28] For detailed studies of the corresponding German situation, see (Trischler and vom Bruch 1999; Ritter et al. 1999; Trischler 2002).

24.4 Modes of Reflection on Globalized Science in the Age of Liberalization

The great pitfalls of science in the twentieth century had made it abundantly clear that scientific innovation is not just an internal matter of science and its irresistible progress. By the 1970s, it had become evident that the very concept of innovation, being an image of knowledge, involves ideas about what science means and where it is leading. These ideas turned out to be as profoundly shaped by science itself as by the world outside science. It had also become apparent that considering innovation without reflecting on its nature as an image of science effectively renounces the freedom to consciously set priorities. The increasingly incisive consequences of scientific progress suggested to take such reflections into account in determining what innovation actually is and what it should be.[29]

The period after the 1970s was characterized by a number of factors. These include the following: the disintegration of the Bretton Woods agreements and the shift to "floating" exchange rates, a "liberalization" of capital and good flows, the emergence of new forms of transnational and domestic governance (the "New Public Management" movement), the emergence of new information technologies, the dissolution of the communist block, the emergence of Asian economies, but also by an increased awareness of the limitations of global natural resources and by the above-mentioned skepticism with regard to scientific progress understood as a self-evident component of modern industrial societies.[30]

It had become clear, in particular, that political, economic or military decisions, but also the market and public opinion, could affect the pathway of scientific developments with long-term consequences. Also, the continued existence of traditional societies still living in the pre-industrial age suggested that the development of human societies is not necessarily linked to an accelerating development of technology, and not at all with the emergence and cultivation of science. Obviously, science was only one of many possible forms of expressing human culture, a realization that suggested approaches to science studies which no longer accept unidirectional concepts of modernity and even doubt the role of science as a privileged form of knowledge.[31]

On a political level, the development of science in democratic societies is exposed to a feedback loop in which it is confronted with the expectations, anxieties and constraints of public opinion. Public and private funding of science in democratic societies requires justification for the investments that may affect the direction of the development or even impose severe limitations on it. At the borderlines between science and society, public images of science are generated,

[29] See (Habermas 1968; Kuhn 1970; Elkana 1974; Feyerabend 1975, 1976). See also the history of the foundation of the Max Planck Institute for the Study of Societies in Starnberg, Germany, in 1970 by Carl Friedrich von Weizsäcker, as discussed in (Leendertz 2010).

[30] For the following, see (Renn et al. 2002; Renn 2003).

[31] See (Latour and Woolgar 1979; Latour 1992; Knorr-Cetina 1981, 1999; Shapin and Schaffer 1985; Shapin 1996).

often amalgamated with religious or ideological components that modulate their interaction. For the non-expert public, it has often been difficult to distinguish between science and pseudoscience, as the spread of creationism, fundamentalist ideas about Islamic science, or Scientology illustrate. As a consequence, the way a particular society can make use of scientific knowledge may be severely restricted. The public accessibility of scientific knowledge and the active participation of science in public dialogue have thus become a major challenge for societies relying on the advancement of science, that is, in the long run, for all human societies.

With the Bayh Dole Act from 1980, for instance, a uniform patent policy was introduced in the US that enables universities and non-profit organizations to register patents for inventions made in federally funded research projects. The intention was to encourage universities to more strongly engage in technology transfer and to increase commercialization, thus strenghtening US economic competiveness. While this policy has led to the creation of thousands of spin-off companies contributing billions of dollars to the American economy, it has also tended to limit perspectives to short-term profits rather than minding the benefits of society at large.

National science policies are increasingly oriented toward international competitiveness. No major society today can permit itself not to foster and regulate science and education systems according to globalized models of schools and universities. Asian universities, for instance, have a strong orientation towards international (American-biased) rankings, such as the Shanghai ranking and the Times Higher Education World University Rankings, and adjust their policies accordingly. The Brain 21 initiative in Korea aims at bringing the ten best Korean universities within the top 100 of the world and to join the world's top ten nations in high-level publications.

Competition is affecting science in the form of the demand to cope with economic globalization, as illustrated by Europe's Lisbon strategy aiming at Europe becoming "the most competitive and dynamic, knowledge-based economy in the world …." In addition, competition takes on the form of a governance mode increasingly used in science management.[32] Incentives are being introduced both on the individual level, for instance by incentive-based management of research by contractually specified objectives, and on the institutional level, for instance by implementing quasi-markets through an increasing competition for third-party-funding and through changing from long-term institutional financial support to short- and mid-term program-oriented financial support.

This encouragement of international competitiveness strengthens globalized models of science and education even more, in particular as they still harbor much of the lore of the Western Enlightenment. But the ensuing globalization of knowledge tends to replace reflection with competitiveness and to downplay the role of specific contexts and local knowledge in favor of supposedly universalist principles of science. Yet it is through this perspective that most societies have

[32] For a discussion of models of science governance, see (Stensaker et al. 2006).

come to view their problems, often disregarding the potential inherent in their own particular traditions or else in the opportunities for changing those principles, opportunities that sometimes only come with a decoupling from global trends and adapting science policy to local conditions.[33]

Science has become, in any case, a medium through which societies of a globalized world reflect upon themselves, albeit often in an indirect or haphazard and sometimes even fatal way. Much of the inner workings of present societies, their economies, their political systems, their cultural traditions and mindsets, and even their mechanisms of biological reproduction, have themselves become the object of science, sometimes with immediate self-regulatory consequences. However, often the most relevant knowledge for a society's future is not generated by its academic institutions, for instance regarding fundamental economic decisions or health care; and if it is available, it is not being implemented because of the incapability of the political system to absorb this knowledge. Nevertheless, scientific knowledge has become an almost unavoidable component of any intellectual attempt to come to terms with human society on a global scale. This becomes particularly evident in attempts to ban, use or even modify science for ideological purposes, as were undertaken under the Nazi regime in Germany or in Soviet Russia. While it has been possible to abuse science for crimes against humanity, it has not been possible to simply abandon science or substitute it with an alternative. The role of scientific knowledge for a society's self-reflection is also clear from the inflation of scientific expertise on issues such as global warming, nuclear policy, energy policy, and national economic policies where conflicting positions are legitimized by expertise and counterexpertise.[34]

Looking back at past images of science, implying expectations for future innovations, their dependence on both cultural values and the limited knowledge available in a given historical situation becomes immediately evident, as it is the case, with the great visions of the end of science, recurrent in history to this day (Horgan 1996). In hindsight, they all appear just as naive as predictions about future technological developments, such as the claim of a popular science magazine in 1949 that, in the future, computers would weigh less than 1.5 tons (Hamilton 1949, 258). But while real innovations often emerge when and where they are least expected, expectations nevertheless have a profound impact on the conditions for innovation. This is because images of science embodying these expectations determine strategies for knowledge acquisition and with them the organizational and institutional structure of science.

Scientific innovation results from a co-evolution of scientific knowledge, images of science, and strategies for knowledge acquisition governed by these images; in short, it depends on the dominant epistemic constellation (see chapter 1). In the current era, the increasingly rapid accumulation of scientific knowledge and the

[33]See chapters 16 and 25. See also (Baracca and Renn forthcoming). The following is based on (Renn et al. 2002).
[34]See, for example, (Oreskes 2010).

growing resources involved in producing it therefore make it necessary to also constantly adjust the strategies for knowledge acquisition and to reexamine images of science that may long have been superseded by this accelerating development. The co-evolution of scientific knowledge, images of science, and strategies for knowledge acquisition is a complex process that has hardly been understood, also because the history of scientific knowledge and the sociology of scientific institutions have been traditionally studied separate from each other.

24.5 The Persistence of the "Classical Image of Science"

For most practical concerns, structures of basic research are still mostly conceived in terms of what one may call the "classical image of science." It has, in fact, become so self-evident that it is hardly conceivable that science could have ever worked without being guided by the distinctions, criteria, and values it imposes. According to the classical image of science, it seems natural, for instance, that one has to distinguish between basic and applied science, that both education and research are organized in terms of disciplines, that great breakthroughs are usually the accomplishments of a few outstanding individuals who publish their discoveries in the most prestigious journals of their fields after the quality of their work has been assessed by their peers. Disciplinary structures which guarantee a competent distribution of labor in science, the identification of innovation with the achievements of individuals, the role of journals and peer review as quality filters—these are all elements of a coherent system of the production and dissemination of scientific knowledge that has indeed worked fairly well in the past.

At present, the system is challenged by several developments that are becoming increasingly dramatic. There is, first of all, the problem of size, both of science itself (in terms of manpower, resources, organization and industrial application) and of the quantity of publications it generates. The tremendous growth of science has been too large for commercial publishers to cope with, forcing certain fields into self-organizing open-access online publication initiatives.[35] The natural and most wide-spread response to this challenge of size is, however, to strengthen the values underlying the classical system of science with the help of an increasingly extended institutional scaffolding, built with the purpose of reinforcing these values by imposing externally controllable criteria. But this externalization of scientific standards has, at the same time, the unavoidable effect of weakening the underlying values by curtailing the significance of the intellectual exchange of the scientific community in favor of mechanisms of social control, replacing, for instance, personal judgements by formal evaluations, reading by counting, quality by quantity. While these mechanisms for steering science still draw their legitimacy from the classical image of science, they have actually produced their own secondary values—always with the danger of degenerating into fetishes such as

[35] See chapter 28.

the impact factor—which encourage the production of more and more publications representing ever-smaller units with the risk of eventually drowning science in an ocean of information, that is, potential knowledge, without assessing its relevance to society at large.[36]

Another dimension of the classical image of science that has become problematic is the assumption that science policy can be sure of its standards of judgement without subjecting them time and again to an evaluation of their adequacy to actual research processes and their real-world contexts. According to the classical image of science, if an evaluation is necessary it is that of science by science organization and not vice versa. Evaluation, like other forms of reflection on science, such as methodology, is a pursuit that to a great extent can supposedly be decoupled from the contents of science; scientific research and science organization belong accordingly to different epistemic spheres, just like content and form, with the latter being largely independent of the former.

However, it has meanwhile become a widespread experience that the interdisciplinary nature of most worthwhile scientific problems makes it necessary to employ resources for tackling them which are usually not readily available as part of the established institutional framework of science or that such problems require reflections on social, cultural and ethical contexts, traditionally reserved to the sphere of applied science. Successfully mastering problems of basic science hence often includes wrestling with issues of science policy. In any case, it may turn out to be a vital problem for basic research if the growing dominance of external criteria of validation, associated with an increasing pressure to legitimize the public resources spent on science, risks obscuring the perception of real problems. Is it indeed always safe to assume that a scientific enterprise which is highly effective if measured by a cost-benefit analysis, holding, for instance, the quantity of publications against the investment of funds, is also actually successful in coping with key human issues, be they questions of survival or simply the quest for knowledge? How can we be sure that the structures of specialized science and of science under the pressure of also quickly rendering economically tangible results do not blind us precisely against those potentials that may offer unexpected pathways to urgently required new solutions?

One of the most salient features of the present historical moment is that the institutional structures of science are permanently challenged by the research process they are supposed to channel, just as most major projects of basic research are permanently forced to reinvent the conditions for their realizability. In addition, they should also be able to reflect their economic, societal and moral contexts, as well as their relationships with other research endeavors. This contrasts with the more or less clear separation of levels of reflection within the classical image of science according to which organizational issues are to a great extent left to administrators, politicians or scientists no longer concerned with research, and where the fixed intellectual framework of a discipline can guarantee that independently

[36] See (Max-Planck-Forum 2003).

achieved results are automatically embedded in the larger whole—even if single specialists are no longer capable of connecting them in their own minds. In short, today's scientists are living in an age that demands participation on all levels of the scientific campaign. This includes its strategic issues, rather than just fulfilling a duty as a private on the battlefield of a specialized discipline, which was all that seemed necessary in the past era of classical science.

After the great pitfalls of science in the twentieth century, from the production of poison gas via the involvement of science in the Holocaust to the development of nuclear weapons, this historical lesson has mostly taken the form of moral appeals to the responsibility of the individual scientists for the application of their insights. At the same time, however, the growing industrialization of science made it increasingly difficult to actually cope with such individual responsibility. As it seems, the twenty-first century now transposes the issue of responsibility in part back into the inner workings of science. When dealing with modern biology, for instance, intellectual issues such as problem definition, institutional and economical issues such as the alternative between open source policy and intellectual capitalism, and moral issues such as the use of stem cells can no longer be adequately divided into small morsels with the idea of assigning separate responsibilities for each of them to biologists, politicians, and philosophers respectively, who then have only to join their specialistic competencies—and, of course, the interests of their lobbies—when meeting in advisory boards or addressing the public.

The interlocking of cognitive, social, cultural and moral dimensions in intricate situations that is becoming the hallmark of science in the twenty-first century is no doubt an additional challenge of complexity but also an opportunity for science to regain intellectual and moral autonomy.[37] Clearly this opportunity can only be used if the freedom of self-organization of science, which is at the roots of its innovative potential, is strengthened rather than weakened by further layers of hierarchical control; if problem choice can be accompanied by reflection instead of being enforced by formalized career patterns; if the necessary reality checks of intellectual ventures are not taken as a pretext for a confinement of science to economically profitable applications; if the social and institutional structures of science encourage intellectual mobility and recruitment from all strata and all parts of a global society rather than the defense of local prebends; and if the new ways of access to scientific information are not blocked by its transformation into a commodity.

This necessity, however, is in conflict with the internal pressure generated by the competition within the worldwide academic system to produce more and ever more specialized results, in general inaccessible not only to a wider public, but also to scientists from other disciplines. The growth of science, as mentioned above, has enhanced tendencies to standardize, institutionalize and automatize many of the control procedures which, at the beginning of modern science, were merely

[37]For studies of knowledge generation based on model systems, cases and exemplary narratives, see (Wise 2004; Creager et al. 2007).

an expression of more or less informal reflections about the quality of scientific achievements within the community of peers. This institutionalization of scientific standards has ensured a high level of professionality and quality control of the scientific production, in spite of its enormous growth and its worldwide spread. To some extent, it has even helped to maintain compatibility and complementarity among scientific results produced in widely distinct branches of academia. But forcing scientific information into small contributions, together with the formalization of quality control and hence of an important aspect of reflection on the meaning of scientific results, has also contributed to the fragmentation and disintegration of science, as well as to the exclusion of important insights attainable only far from the mainstream, not to mention the lost opportunities to tackle grand challenges transcending any disciplinary borders.

24.6 The Formation of Socioepistemic Complexes and the Onset of Socioepistemic Evolution

The globalization of knowledge today is a consequence of two processes: the intrinsic globalization of science and the fundamental role that knowledge, particularly scientific knowledge, has assumed in other, economic, political and cultural globalization processes. As for the first process, we have seen that the globalization of science has become a self-organizing, global distribution of intellectual labor, reshaping national institutional structures and local epistemic traditions. At least in the natural sciences, a global epistemic community has emerged with common standards, concepts and methods. Yet, as we also stressed in previous chapters, globalized science results from a synthesis of many local traditions and not from a single dominant Western model, and these local contexts continue to play a non-negligible role. The process in which globalized science emerged is deeply historical and dependent on contingent contexts and chance constellations, which, in the course of history, are transformed into necessary preconditions for further development.

As for the second, extrinsic process concerning the role of knowledge in other globalization processes—whether political, economic or cultural—it is evidently the case that any flow of scientific knowledge that comes to be associated with the international policy of individual states or with multinational actors, such as NATO, IBM, UNESCO, Al-Qaeda (e.g., by funding or espionage), unavoidably takes on a global character.

A critical link between intrinsic and extrinsic aspects of the globalization of scientific knowledge is found in the media and types of communication in science, which are the currency of an epistemic economy. Another critical link is the mechanisms of effective knowledge transmission between science, policy and society. Effective knowledge transmission means not just making knowledge available to different target groups, but at the same time creating conditions for implementing knowledge in practical contexts. As we showed in chapter 16, when transmitted to a different sociocultural environment, supposedly global knowledge, such as knowledge about central banking, may acquire a different meaning and be used for different purposes.

One important result of the interaction between intrinsic and extrinsic processes of the globalization of knowledge in the long twentieth century, that is in the period between ca. 1870 and today, is the emergence of global objects of science, in particular global human challenges such as climate change, scarcity of water, global food provision, reliable energy supply, sustainable demographic development and nuclear proliferation.[38] Dealing with these global themes, scientific fields including meteorology, seismology, oceanography, environmental science, epidemiology, earth system sciences, astronomy, space-bound science but also sociology, political science and economics necessarily operate on a global scale.

The mitigation and handling of global challenges to humanity are inherently connected, both to the development of policies and to the production of scientific knowledge on a global scale. Here, policies do not just shape the organizational form of science and determine research priorities—while there is, for example, an Intergovernmental Panel on Climate Change (IPCC) dealing with climate change, no comparable organization exists for dealing with the challenges of energy supply. Scientific knowledge also crucially shapes policies and politics. But it is as yet unclear which international arrangements are most effective to encounter collective international problems, which arrangements actually bring about scientific advancement, how international coordination enables the establishment of specific international research projects, whether global coordination is under all circumstances favorable to the advancement science, when globalized science serves as an ideological tool for legitimizing collective political actions and when it actually becomes a resource structuring international regimes, shaping global images of knowledge or enabling new forms of global governance.

It is evident that no simplistic rationalistic-technocratic model of policy-making according to the scheme of "speaking truth to power" adequately describes the current situation. It is generally not the case that science first identifies a problem then offers a solution that politics finally has to implement. Such a procedure does not reflect the actual dynamics of coping with these challenges. Neither is "truth" produced in an area free of interests, values and uncertainties, nor is "power" simply adopting and implementing knowledge free of normative considerations.[39] Some approaches therefore see "epistemic communities" in a decisive role for triggering processes of learning in policy-making and beyond.[40]

More specifically, socioepistemic complexes have formed that involve such communities in the production of scientific knowledge in large-scale technological ventures, in global infrastructures and regulations, or in worldwide operating

[38] For the example of global food provision, see (Nützenadel and Trentmann 2008); for the problem of water supply, see (UNESCO 2009); for other challenges, see the remainder of this book.
[39] See (Oreskes 2010).
[40] See, for example, (Haas 1992). See also (Silberglitt et al. 2006; Ozolina et al. 2009; Rockström 2009).

enterprises. They may still largely depend on traditional sociocultural modes of knowledge generation, but they may also create new modes, such as that embodied in the collective production of open source software. These socioepistemic complexes cause changes on a global scale that cannot be easily undone. Examples are the global networks of nuclear technology, of mobility, or of information and communication. Governance of such socioepistemic complexes requires the production of more and more scientific knowledge. They even endanger their ecological and social substrata unless new scientific knowledge continually becomes available. As a consequence, they sharpen the dilemma of human freedom, increasing humanity's potential to act but making the world increasingly dependent on the appropriate use of this potential.

It is thus a further consequence of the interaction between intrinsic and extrinsic processes of the globalization of scientific knowledge that sociocultural evolution in general, including economic and political globalization, becomes more dependent, both on the production of scientific knowledge and on the possibility of coping with the global challenges for humanity mentioned above. This growing dependence, mediated by global socioepistemic complexes, may be characterized as a new stage in human development, as a socioepistemic evolution.[41] We speak here of evolution in the general sense of a developmental process that is not determined by its starting point, but that constantly transforms contingent circumstances into unchangeable prerequisites for further development so that the process acquires memory. The contingent circumstances come from the environment of the process, but they may also be generated by the process itself so that the development becomes indeterministic and its outcome unpredictable.

As a consequence, such an evolutionary developmental process is an interactive learning process of a very general kind in which extrinsic features of the environment are internalized, at the same time, the environment itself is transformed by the developmental process, accounting for its self-referential character. The interaction between a developmental process and its environment can take different forms. In biological evolution, the generalized learning process takes the form of variation and natural selection. In sociocultural evolution, it takes the form of human interaction with nature by means of material artifacts, associated with the accumulation of knowledge shared within a given society. In socioepistemic evolution, it takes the form of humanity's interaction with its planetary environment by means of a globally effective material culture (determining a developmental stage characterized as anthropocene), associated with the accumulation of globalized scientific knowledge.

Socioepistemic evolution is the process in which the global production of more and increasingly diversified scientific knowledge about humanity's interaction with nature becomes critical for its survival. In the Paleolithic age, sociocultural evolution took over from biological evolution in such a way that the human species has become dependent on it. Meanwhile, the generation and transmission of scientific

[41] See the discussion in chapter 1.

knowledge has similarly become quintessential for human survival. The demand to produce the appropriate scientific knowledge may exceed the potential of traditional modes of the generation of knowledge in sociocultural evolution, such as state-supported basic research or market-driven applied research, and necessitate new forms of knowledge production. Some of these new forms of knowledge production are emerging in connection with the socioepistemic complexes marking the transition from sociocultural to epistemic evolution, such as the global knowledge production associated with the World Wide Web. But just as there were—and are—many pathways of sociocultural evolution (from clans, feudal systems, state bureaucracies to market economies—with or without democracy), there are and also will be a variety of pathways into socioepistemic evolution, paradigmatically represented by some of the developments discussed in the following.

24.7 The Perspectives of Social Studies of Science and of Historical Epistemology

The recent changes in higher education and research associated with globalization processes are also the subject of theoretical approaches from the social studies of science. While it is argued that we are facing a dramatic change of science as a social and cognitive system, comparable to the transformation accompanying the Industrial Revolution, the long-term historical origin of these changes tends to be neglected and the dichotomy between "old" and "new" science is overemphasized.[42]

Also, the transformation of the academic world is conceived not so much in terms of a globalization of knowledge with its own dynamics, but rather as a consequence of economic globalization, for instance, as a reaction to rising societal demands to gain revenues from publicly funded science in an increasingly competitive world. The "new" science is characterized as "mode 2" (Gibbons et al. 1994; Nowotny et al. 2001), as "post-academic science" (Ziman 2000), as "post-normal science" (Funtowicz and Ravetz 1993), as "academic capitalism" (Slaughter and Leslie 1997) or in the context of the "triple helix" model of university-government-industry relations (Etzkowitz and Leydesdorff 1997).

For our discussion here, however, it is less relevant whether a clear separation of the spheres of academia and society has ever existed in the past (mode 1 science), or whether knowledge in the future will really be produced by interdisciplinary task forces addressing problems of social and economic importance, such that scientific disciplines will vanish (mode 2 science). What characterizes epistemic evolution is the transformation of the production of scientific knowledge from a contingency of sociocultural evolution into a necessary condition for human survival, whatever specific form of science is involved and whatever mode of knowledge production may ultimately turn out to be suited to ensure that survival.

Without more detailed studies taking into account not only sociological but also epistemological and historical dimensions of the global development of science

[42]See, for example, the critique in (Weingart 1997; Pestre 2000; Shinn 2002).

and technology, overall trends will be difficult to assess. The development and diffusion of knowledge in modern science is, in any case, not just subject to unidirectional tendencies of growth, expansion, specialization and commodification, although the commercialization of science has reached a new quality and intensity being intertwined with a globalized market. There are even strong tendencies in the opposite direction, for instance the growing recognition of the importance of open access, knowledge sharing and collaboration not impeded by a narrow interpretation of intellectual property rights. Also, the standard picture of an ever expanding science ignores the fact that even where scaling-up processes prevail, they may actually be due to quite diverse developmental processes of the different branches of science in interaction with its environment.

Clearly, the ever increasing differentiation of science is counterbalanced by overarching knowledge integration and unification processes as in the convergence, at least with regard to certain problems, of physics and chemistry, and chemistry and biology. However, the potential of such unifications as a countervailing force to knowledge fragmentation has typically met with a number of extrinsic obstacles, in particular linguistic, cultural, economic, juridical as well as political and ideological constraints. At the same time, there have been intrinsic obstacles, such as the gap between theory and data existing in such fields as economics, the neurosciences, psychology and surface physics.

More generally, it has turned out to be difficult, given the past success of seemingly universalist principles in science and their implementations, to take into account the possibility that different contexts may necessitate different ways of conceptualizing and implementing scientific knowledge. Reflecting on these contexts is also difficult because knowledge is embodied in different forms of representation: in institutions, individuals, instruments, texts and images. These various vehicles are subject to different interfaces between science and its environment and have different implications for the mobility or "liquidity" of the knowledge they carry. As we have emphasized above, each field of science may have its own characteristic trajectory of recursive blindness that may also affect the potential for its integration into other fields.

In psychology, for instance, we often still witness a rather artificial separation between studies focused on the individual under more or less universalist perspectives, from studies of the social, cultural and psychological context of individuals and collectives. Similarly, in economic studies, the role of distinct historical pathways and cultural settings still tends to be neglected in favor of simplified assumptions about a more or less bounded rationality.[43] The humanities are just beginning to avail themselves of the possibilities to overcome traditional disciplinary boundaries in favor of integrated accounts bringing together their sophisticated reflective traditions with the wealth of data that is now becoming available and, due to the progess of information technologies, manageable. Physics was in the past characterized by successful integration processes resulting in seemingly universal

[43]See the discussion in (Kahneman 2011).

principles and foundational concepts. In the future, these integration processes may depend also on a more explicit reflection on its proliferation into diverse subfields, the concrete contexts of its multifaceted applications, and their repercussions of these processes on the conceptual organization and unity of physics.[44]

The globalization of modern science involves various types of knowledge. In addition to the classification outlined in the general introduction (chapter 1), one may distinguish between knowledge systems related to the classical disciplines, knowledge systems related to socioepistemic complexes, and second-order knowledge embodied in science policy and organization. One may also distinguish "truth-oriented knowledge" from "technology-oriented knowledge" on the basis of its ethos of autonomy in relation to political institutions and market demands. It is manifested not so much in the actual autonomy of knowledge but rather in the tendency of knowledge producers to demand such autonomy and to legitimize it. "Policy-relevant knowledge" has direct implications for policy making and governance. Policy relevant knowledge is built on truth- and technology-oriented knowledge. For example, nuclear physics started as truth-oriented knowledge, and later on assumed technological and policy implications. The passage from one type of knowledge to another evidently also affects the modes of production and distribution of knowledge. Each of these types of knowledge is likely to be distributed by a different transfer mechanism: truth-oriented knowledge by epistemic networks, technology-oriented knowledge by market mechanisms and policy-oriented knowledge by hierarchical mechanisms.

Scientific knowledge itself comprises several layers: familiarity with elaborate theoretical frameworks, largely documented in texts, with methodologies, often only implicit in scientific practice, and technological knowledge about handling relevant equipment. Scientific knowledge is furthermore accompanied by meta-knowledge about the meaning and goals of science, its role in society, its relation to other pursuits, its organization, and so forth. Scientific practice would, however, be impossible without also involving intuitive and practical knowledge of the most diverse kinds, from social competence via manual dexterity to language skills or the ability to handle complex symbol systems. Since scientific practice does not take place in isolation but is embedded in specific cultural, social and technological environments, one also has to pay attention to the knowledge related to these environments and the ways in which it intersects with scientific knowledge proper. If we consider science in action, all of these types of knowledge play a role.

The globalization of modern science affects them in different ways. Different fields of science rely, for instance, in different ways on language skills: in general the humanities depend on it more than do the natural sciences. Consequently, the spread of scientific knowledge may become affected by the worldwide distribution of linguistic competence in the lingua franca of a given field. Since science has a different status in different societies, the transfer of scientific knowledge inevitably involves a transformation of meta-knowledge with possible repercussions on the

[44] See the discussion in (Galison and Stump 1996).

body of knowledge as well. But scientific knowledge transferred to another context may also be confronted with different technological environments, leading to new insights or hindering the reproduction of ones already achieved in new locations.

It may thus appear that the transfer of scientific knowledge to diverse environments almost unavoidably leads to a splintering, which may even risk endangering its coherence, in a way similar to the splitting of a language as a consequence of the spreading and separation of its speakers.[45] But similar to the case of a language which is preserved intact during such a process, in science it is the continued exchange and equilibration processes among the community of its practitioners that make sure that globalization works in general toward a differentiation and enrichment rather than toward speciation. In addition, one has to realize that it is rarely single components of scientific knowledge that are being transferred, but almost always systems of knowledge. As a consequence, scientific knowledge displays a self-organizing capacity in transfer processes, making it possible to reconstruct it even from fragments if necessary. Yet because what is thus reconstructed is not necessarily a true copy of the original, this self-organizing capacity becomes another source of the diversification of scientific knowledge in globalization processes (see chapter 9).

24.8 Pathways to Socioepistemic Evolution

In the chapters that follow, different pathways of the development of globalized science are analyzed, representing different constellations of knowledge, economic structures, societal regulations and policies, as well as challenges to human survival. Thus, the politically regulated dissemination of Big Science-based technology of a dual-use character is compared to the bottom-up global distribution of labor in Big Science without such dual-use implications.[46] In addition, different models and motivations for the globalization of science are examined. While local hubs of science have attracted international researchers in the development of molecular biology, the Conseil Européen pour la Recherche Nucléaire (CERN) was set up with the explicit purpose of facilitating the maximum possible international cooperation in high-energy physics.[47] The IPCC mentioned earlier was instead set up with the intention to assess knowledge about climate change and provide advice for policy makers.[48] The challenges of global energy supply evidently require bringing together competencies from natural science, technology and the social sciences on an unprecedented scale.[49] The complex interplay between national and international aspects of science is considered in fields as diverse as psychology and molecular biology.[50] A specific aspect of this interplay is the differing

[45] See (Thiering 2009). See also (Foley 2010; Coupland 2010).
[46] See chapters 27 and 28.
[47] See chapters 28 and 29.
[48] See chapter 31.
[49] See chapter 30.
[50] See chapters 26 and 29.

roles of science policy together with its cultural, political, economic and military motivations.

24.9 Nuclear Physics and the Emergence of Big Science

One example for a contingent scientific discovery leading to a large-scale societal transformation was the insight into the feasibility of nuclear fission which was achieved by Otto Hahn, Fritz Strassmann and Lise Meitner in 1938.[51] It amounted to the discovery of a new way of harvesting energy from matter.[52] The military and economic impact of this discovery, in connection with the economic, political and military catastrophies of the twentieth century, fostered the worldwide establishment of Big Science.

Nuclear energy is unique in being the only significant source of energy not of solar origin. It would not have been possible without basic science and its unpredictable consequences.[53] Its economic and military significance today, however, is due to a targeted industrial revolution, as demanded by those concerned with the climate challenge.[54] This targeted industrial revolution may go back as far as the Roosevelt plan in the Great Depression, but gained momentum only with the emergency situation of World War II and the Manhattan Project to produce the atomic bomb.

This case shows a particular pathway along which a by-product of sociocultural evolution—atomic science—may lead to socioepistemic evolution. We call this path the "Manhattan Path," turning basic science to military and civil use via a gigantic engineering venture. It created not only a new technology, but also a new kind of socioepistemic complex of knowledge, technology and social structures, which, for all we presently know, is here to stay whether we like it or not. Given the dangers of even natural radioactivity for human life, the technology is intrinsically dual-use. Even if we were to eliminate the technology, the knowledge about nuclear explosives would stay with us and can easily be reproduced.

Also, the enormous quantities of radioactive materials remain with us in any case: the global stockpile of highly enriched uranium is about 1800 metric tons (IPFM 2007, 7) and each year about 10,000 metric tons of spent fuel are discharged from nuclear reactors worldwide (Feiveson 2007). And the military industrial complex, as an outcome of the Manhattan Path, is also here to stay: the five biggest defense companies in the United States employ more than half a million people and generate over 80 billion dollars per year (Hennes 2003).

Since the knowledge they produce can no longer be eradicated or even confined, it can only be controlled if further knowledge is developed, for instance,

[51] See (Hahn 1968, 150–157; Lewin Sime 1996, 161 ff.; Morgenweck-Lambrinos and Trömel 2000; Kant 2002, 88–92; Sexl and Hardy 2002, 88 ff.; Lemmerich 2004).

[52] See chapter 27. See also (Hennes 2003; Lavoy 2003; Feiveson 2007; IPFM 2008a).

[53] Thomas Kuhn discusses in detail the difference between basic and applied science in (Kuhn 1959).

[54] See chapter 31.

about political mechanisms, about possibilities for cooperation in alternative energy scenarios, and also about the dynamics of national pride.

In fact, only control by means of second-order knowledge can serve as a regulative of the spread of knowledge with dual use potential. But such second-order knowledge comes in the form of technical control and in terms of global regulations. It means to recognize the liquid quality of knowledge, seaping through any barrier. Confinement of knowledge by secrecy can ultimately only have a retarding effect. Such delays may, however, be important for creating windows of opportunities for alternative scenarios, for example, keeping Iran from acquiring atomic weapons long enough to find either a political or technical solution to its energy problems.

24.10 High-Energy Physics as an Example of Impartial Big Science

Like nuclear technology, high-energy physics emerged as basic science that at some point gave rise to unpredictable spin-offs.[55] High-energy physics is essentially the science of subatomic particles, an expensive venture with little immediate economic or social impact. Higher and higher energies are required to penetrate deeper into the structure of matter, and hence, larger and larger facilities are needed. The huge European laboratory CERN in Geneva, set up after World War II, is one of the best known examples.[56] CERN demonstrates the possibility of large-scale international cooperation on knowledge production under the boundary conditions of an absence of immediate political, military or economic implications. Not least for this reason, it has become a test ground for a new global knowledge infrastructure. The Web was invented at CERN, grid computing is being developed at CERN, and the open access movement was initiated at CERN. CERN illustrates another pathway to socioepistemic evolution.

In spite of the enormous investment in this institution, the significance of its ongoing knowledge output for fundamental physics, its role as a driver of information technology and as a model for international scientific cooperation, it is nevertheless conceivable—for political or economical reasons—that such an institution is no longer funded.[57] Some of CERN's achievements, however, in particular the World Wide Web, can no longer be abandoned without devasting consequences. Once again, it becomes evident that large-scale knowledge production ventures tend to have irrevocable sociocultural consequences. In fact, it is hardly imaginable that the future development of the global knowledge infrastructure can succeed without the continued production of scientific knowledge.

In view of the impartiality of high-energy physics with regard to immediate economic or military interests, other than concerns of prestige, one may prefer

[55] See chapter 28.

[56] For a historical account, see (Hermann et al. 1987).

[57] See the case of the Superconducting Super Collider which was terminated for economic and political reasons in 1993 (Riordan 2000).

the "CERN Path" rather than the "Manhattan Path" to socioepistemic evolution. The question that remains open, however, is whether this experience can be transferred to other areas where large-scale knowledge production is urgently needed, for instance, in the domains of climate research and energy supply, but where—in contrast to high-energy physics—strong political and economic interests may condition or even constrain necessary knowledge production.

24.11 Climate and Energy Challenges and the Quest for Socioepistemic Evolution

There is a broad consensus that global warming represents a global challenge.[58] There is also an emerging consensus that an adequate response requires a large-scale transformation of industry within the next half century or so, a transformation that has been discussed as another industrial revolution. In order of magnitude, this industrial transformation will be comparable, at least, with the transformation of the US economy during World War II, without, however, having the driving force of a generally perceived emergency situation at its disposal. Probably the most critical element of the required industrial transformation is the future energy supply system. It will have to be developed from the present situation through various steps, each requiring new knowledge and considerable social and economic adjustments. At present, after decades of effort, the proportion of solar energy in the global energy supply is still vanishingly small, much less than 1%, although the total energy supply from the sun would suffice for all our energy needs. Nuclear energy supply hovers at around 6%; its scaling up to a significant contribution to the global energy challenge seems unrealistic.[59] The proof of principle of fusion energy remains decades away. In addition, all development processes of new technology, from the proof of principle to industrial implementation, take a long time. For instance, it took more than sixty years to go from a pilot model to the first one-megawatt power plant. On the scale of what is needed, some of the present attempts to solve the problem seem rather helpless. Biofuel, for instance, has little relevance for energy supply but a large unpredictable impact on food markets. All concepts of future energy supply must be designed and verified in light of their impact on the various biological and physico-chemical regulatory systems on earth. In short, the challenges of climate and of energy result from sociocultural evolution, but cannot be successfully addressed without significant steps into socioepistemic evolution.

In the case of the energy challenge, the need for more knowledge is particularly evident, as is the problem of its generation under the circumstances we know.[60] The energy problem is so complex that research cannot prematurely focus on a single direction. Moreover, research has to proceed with attention to technical

[58] See chapter 31. See also (Rahmstorf and Schellnhuber 2006; Rockström 2009; WBGU 2009).
[59] See (Renn et al. 2011) and chapter 30 in this volume.
[60] See chapter 30. See also (Gruss and Schüth 2008).

challenges, and it has to work with alternative generalized energy supply scenarios, which analyze the resulting systems in terms of bottlenecks. At the same time, one has to take into account the boundary conditions of scalability, sustainability and climate compatibility. The difficulty of achieving effective chemical energy storage with present technologies, for instance, is the single largest bottleneck to the widespread application of solar energy.

Some argue that what is needed is a huge concentrated international research and development effort, on the scale of the Manhattan project or CERN.[61] Possibly a new international research and development center on energy chemistry could be set up, or a single strong nation may go ahead, setting new standards. It would also be necessary to include and study past experiences with major reorganizations of energy supply systems. But the resistance of the existing energy providers to any system change will be considerable and most likely have an impact, even on the level of research. In view of the socioeconomic impact of each generalized conclusion drawn from such research, the greatest challenge is therefore to enable necessary, unbiased knowledge production on a large scale, and hence to free this pathway toward socioepistemic evolution from some of the limitations of sociocultural evolution.

24.12 Molecular Biology and Genetic Engineering as Pathways to Socioepistemic Evolution

Molecular biology illustrates yet another pathway to socioepistemic evolution.[62] Starting in the 1930s, international scientific cooperation emerged, not through central planning, but rather as a bottom-up phenomenon. A decisive role was played by a few hubs in the initially rather thinly spread network of scientific cooperation. These hubs were formed by laboratories with unique pieces of equipment or with a unique combination of personal competencies. They served as catalysts for integrating knowledge from a diverse array of disciplines. Gradually, a global research landscape emerged. Just as in the CERN case, though, the practical irrelevance of the scientific knowledge produced kept the network open for a seamless flow of knowledge and personnel. This was the golden era of molecular biology. Imagined or real opportunities for engineering and commercial applications emerged only later. This new perspective encouraged large-scale organized cooperation, such as the human genome project, but also gave rise to a new fragmentation of knowledge production due to commercial and cultural boundaries. In genomics and other life sciences, commercial opportunities and patenting have meanwhile achieved a significant impact on research communication. A survey of 3000 geneticists and other life scientists found that 44% of geneticists and 32% of the other life scientists withheld data (Blumenthal et al. 2006).

[61] See chapter 30. See also (Renn et al. 2011).
[62] See chapter 29. See also (Novotny et al. 2006; Khushf 2007).

The new socioepistemic complexes emerging in connection with the life sciences, and in particular with the possibilities of genetic engineering, confirm the insight that the creation of scientific knowledge has irrevocable consequences, in this case on the future of the biological development of our species, as well of the biological substratum on which we depend. The industrial organization of the food chain, for instance, may become critically dependent on socioepistemic complexes with their own, unpredictable behavior. This may lead to a lasting change in the economy of knowledge, and in particular, to a shift between private and public domains of knowledge. Knowledge involved in the age-old cycle of seeding and harvesting used to be public knowledge. But as seeds become products of genetic engineering, rather than public knowledge, agricultural production will become increasingly dependent on privatized knowledge subject to market economy (Mulvany 2005).

24.13 Global Health as a Challenge to Sociocultural Evolution

Diseases are not only part of our biological evolution, they are also part of sociocultural evolution.[63] They have emerged, for instance, from contact between humans and animals in domestication processes. One example is smallpox, which was transferred from rodents to humans some millennia ago in the age of the Neolithic Revolution. Today global traffic, global nutrition chains and global inequalities in living conditions have set a new stage for the emergence and spread of bacterial and viral diseases. Diseases may constitute challenges that affect societies and economies on a global scale, even if they do so in extremely different ways in different parts of the world. Knowledge produced in the traditional mode, that is, as a by-product of sociocultural evolution, by basic research and market-driven innovations, may turn out to be inadequate to cope with these challenges. The global pharmaceutical market, for example, is dominated by the production of drugs for the "First World."

The challenges of the major diseases of the developing countries, such as tuberculosis, malaria and AIDS, are not only economic in character, they are also challenges for the production and transmission of knowledge. It is an evident truth that millions of HIV sufferers in developing countries cannot afford drugs at the current price level of the First World market. What is less well known is that pharmacological research and industry has for decades failed to generate the very knowledge for producing urgently needed drugs that might help to eradicate the major diseases of the developing countries. Among the 1400 drugs licensed in the last decades of the twentieth century, just three were for treating tuberculosis, four for malaria and thirteen for all the neglected tropical diseases together, whereas 180 were approved to treat cardiovascular diseases.

Such neglect begins to take its toll. In the case of tuberculosis, the knowledge for diagnosing and vaccination is about a century old and has not been substan-

[63] This paragraph draws on (Kaufmann 2008, 2009). See also (Benatar et al. 2005).

tially augmented since this time. While knowledge about how to treat this disease has not progressed, the disease itself has. New forms of multidrug resistant tuberculosis have evolved. Without making significant progress in drug development, the first decade of the twenty-first century will see 100 million cases of multi-drug resistance tuberculosis leading to 20 million deaths. This is a global challenge. There are no health sanctuaries; the disease has returned again to Europe. Among the twenty countries with the highest rate of multidrug resistant tuberculosis infections, fourteen are European. New forms of knowledge economy are needed to create the required knowledge as well as the structures for its transmission and appropriation. Incipient forms of this knowledge economy comprise the acceleration of the admission procedures for drugs relevant to developing countries, new patent legislation tuned to social rather than economic relevance, and "debt for health" policies aimed at fostering the development of health systems in poor countries. It is important to realize, however, that knowledge is neither a raw material nor a commodity that can simply be produced and brought into circulation at will.

The examples discussed so far have illustrated that the great challenges of humanity confront us with a structural deficit of knowledge. The existing modes of knowledge production and dissemination will probably be insufficient to cope with these problems. While socioepistemic complexes make the world as we know it increasingly dependent on scientific knowledge, they may nevertheless be incapable of delivering the required knowledge. Hence, socioepistemic evolution confronts us with a sheer unmanageable complexity of societal and epistemic interdependencies and with new opportunities to cope with this complexity. Its relation with a further-going globalization of knowledge is evident, but many other features are still unclear. What is clear, however, are its demands on a global knowledge infrastructure.

24.14 Toward a Global Knowledge Infrastructure

In our review of current trends in the globalization of science, we therefore finally address the developments toward a global information infrastructure, which is made possible by the new information technologies.[64] It was already envisaged in the early 1960s, with Ted Nelson's idea of a global hypertext, to potentially represent the collective knowledge of humanity in a new way, as mutually linked texts. It was realized only in the late 1980s, when the World Wide Web was developed—initially as a communication platform for physicists. Only then did the general idea meet with the technical competencies to realize it.

The Web offers a completely new way of representing knowledge. Information provided by single individuals can have an unprecedented worldwide impact. As Wikipedia and other projects illustrate, the Web allows for an equally unprecedented cooperative scalability, enabling the cooperation of thousands of individuals on the production of knowledge. The Web offers nearly universal connectivity, in

[64] See chapter 32.

principle linking every document with every other document. The Web has exceptional plasticity, allowing the available information to be corrected or reorganized quickly. The Web allows information to be found quickly, and it has a very low latency such that the production and dissemination of information are no longer separated by large time intervals. Today's social, economic and scientific reality has become unthinkable without the Web. In principle, for the first time in history, it allows for a global, dynamic representation of human knowledge with a strong, self-organizing potential. The universal access to information that it offers may thus serve as a significant catalyst for a globally connected and well-informed public opinion, serving as a driver and corrective for political and economic decision making.

However, the Web is also characterized by the fact that hardly any of these potentials are actually realized in its present implementation. There are even risks that it will degenerate more and more into a platform where information is advertised and commercialized, rather than being made openly available and effectively interlinked with other information. Visions such as those of the Semantic Web or open access to scientific information and cultural heritage are far from being realized. And what is actually needed to realize a global knowledge infrastruce goes far beyond these visions: an Epistemic Web, a Web optimized for the representation not just of information, but also of knowledge.

The Web as a new socioepistemic complex is thus no different in principle from the other such complexes we have been considering. Born as an unexpected by-product of sociocultural evolution, it has created a reality which can no longer be imagined without it, and it has opened up a new route into socioepistemic evolution. As with the other cases, the Web confronts us with technical problems, such as bandwidth and speed, as well as with social problems, such as the so-called digital divide, the unequal distribution of Internet access in the world. But all socioepistemic complexes also confront us with a political challenge, not only to employ knowledge to shape our world, but also to shape a world in which the scientific knowledge that is urgently needed can be produced and made available to whoever may best put it to use. In the case of the Web, however, there is yet another dimension. In view of the interaction between structures of knowledge and the media serving for its external representation, it is to be expected that the Web, as a medium with radically new properties, will have a profound impact on the future organization of scientific knowledge as well. In order to assess this potential, one has to take into account the complex architecture of this knowledge and its liability to change in the process of globalization.

24.15 Science as a Medium of Reflection for a Globalized World

We have stressed above that, even in disciplinary science, reflective thinking has played a decisive role in guiding reorganizations of theoretical and institutional structures made necessary by the accumulation of new knowledge. In dealing with the grand challenges of present science and technology, such as energy and climate problems, with a future information infrastructure or with the issues raised by global health and genetic engineering, reflective thinking may take on a novel and even more central role. It will have to reveal some of the implicit assumptions through which basic science depends on past and present contexts, assumptions that are not easily visible in the canonical disciplinary accounts and whose tacit acceptance may represent a hindrance to deeper insights, in particular when contexts are changing.

Making a reflective approach part and parcel of scientific practice to a far greater extent than is presently customary will also be crucial for regaining intellectual autonomy with regard to those large-scale socioepistemic complexes emerging in the process of socioepistemic evolution. The systems of knowledge associated with them are much more heterogenous than those familiar from the classical disciplines, not only spanning various of these disciplines but also comprising complex social and economic structures as well as power relationships that are rarely made explicit. Competence in governing these socioepistemic complexes is hence typically distributed over various levels of intellectual and political interactions. These interactions are plagued by the familiar difficulties of interdisciplinary cooperation and the incompatibilities between scientific and political agendas.

A more widespread acceptance of a reflective approach to science, making explicit its historical and epistemological premises as well as its susceptibility to political and economic influences, may help to address these difficulties. Developing and spreading such an approach may, however, also be associated with at least partially reorganizing the primary, first-order knowledge content of the sciences and thus ultimately transcending classical disciplines. It may indeed turn out that mastering the intellectual and political challenges of socioepistemic complexes requires bringing together large, multidisciplinary conglomerates of knowledge and meta-knowledge. It could also turn out to be useful to identify those smaller units of knowledge that may serve as starting points for their reorganization.

Hints at such a development are evident in the new forms of organizing knowledge emerging in the context of the Web, illustrating how this new medium may transform science in future globalization processes. Remarkably, some of the most effective forms of organizing knowledge on the Web actually go back to traditions preceding the establishment of the disciplines, such as the encyclopedia tradition revived by Wikipedia or the cosmographic tradition, organizing knowledge according to space, revived by Google Earth and other geographic information systems. But in spite of this rather old-fashioned appearance, their innovative features correspond precisely to the expectations formulated above, displaying information in smaller units and larger contexts at the same time, and making it more flexible and more susceptible to reflective change by exposing it to a global, interactive evaluation. There are and will be other models of organizing knowledge, making even more effective use of the interactive features of the new medium. But it is, of course, hard to predict in detail which epistemic models of future science might result from the encounter of the grand challenges described above and the potentials offered by the new medium.

The parallelism between today's Internet revolution and the printing revolution of the Renaissance has often been emphasized. It is, however, less conspicuous to what extent this revolution does not just represent a technological breakthrough, but also challenges the structures of knowledge organization which may have to be partly reinvented in light of the novel potentials rather than just being translated into the new medium. The analogy of our present situation with the age of the Scientific Revolution is, however, not limited to that of a comparable innovation of media. It rather seems that another comparable feature of both historical moments is represented by the prominence of great challenging problems requiring new forms of knowledge integration. In the early modern period, the challenging objects of science were generated by the great engineering ventures which made it necessary to assemble all knowledge resources available, from Greek mathematics to the practical experience of contemporary engineers.

In our period, the grand challenges are instead represented by the problems encountered in the aftermath of the great civilizatory ventures (and their pitfalls) initiated in the early modern period. Today's challenges no longer concern just the local fate of city states but—via the grand socioepistemic complexes emerging with socioepistemic evolution—also unavoidably the global society. Characteristically, the overarching perspective required by some of the outstanding challenging problems of today is therefore no longer one of infinite horizons and new worlds, but one focusing on the limits and the intrinsic complexity of systems, whether these are of an ecological, societal, cognitive, or cosmological nature. Compared to the early modern period, the main concern of the present is no longer one of universalizing the local, but of localizing and contextualizing the supposedly universal.[65] We are no longer compelled to categorically segregate culture from nature but be able to realize that these categories may be inescapably mingled, and not just by setting each other limits or standards. In the Renaissance the grand challenges were addressed by outstanding intellectuals who were unrestricted by academic or guild traditions, by great individuals such as Leonardo, Kepler or Galileo. While the historical moment of such universalist thinkers may have passed, there can nevertheless be little doubt that, at present, we need no less courage to transgress established boundaries, both on the individual and institutional levels, to explore the potential of the knowledge resources divided by these boundaries and to exploit the potential of science as a medium of reflection for a globalized world.

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[65] See (Morin 2001; Sloterdijk 2005; Tomasello 2009; Habermas 2011; Sloterdijk 2011; Hessel and Morin 2012). See also chapter 25 in this volume.

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Chapter 25
The University of the 21st Century: An Aspect of Globalization

Yehuda Elkana

25.1 Introduction

"Globalization" has become a buzzword. When discussing it, the spectrum of views moves between seeing in every aspect of life an aspect of globalization and the view that there is nothing new about it: it was present in some form in all periods of history. In a way, both claims are true and we need some conceptual fine-structuring in order to make our point.

If we mean international trade or spread of inventions, of other types of new ideas or of knowledge in general, it existed from ancient times. On the other hand its scope and depth today is unprecedented and it is universal. In a very real sense the world has become one: political ideas, social institutions, universities have all become globalized as we shall see below.

While under "globalization" for a while mainly economic matters and new techniques of communication were meant, it soon became evident that many other aspects, like, for example, political ideologies, also became globalized. Democracy has become much more widespread in the last decades than ever before, but even more than actual democracy, it is the language—the political discourse—which became globalized. When listening to politicians representing genuine democracies, military dictatorships, communist one-party systems, fanatic theocracies, they all sound the same, evoking the same slogans, quasi the same ideals.

Yet, what was feared by many, of the world becoming an undifferentiated flatland, using a universal bad English as means of communication, has not materialized. On the contrary, all those aspects which did not fall under the aegis of economic interests, or were not part of a universal IT-system, became locally emphasized and cultivated more than before: local cultures, religions, languages, traditions and so forth.[1]

Curiously, the university belongs to the first category: hundreds of new universities in the world, most of them in India and China, are mushrooming, all built on the model of the university as it has developed in the West in the last hundred years. By now, the fact that they were developed in the West has lost much of its meaning, or its political overtone, but the basic similarity of all of them

[1] On this double nature of globalization, see Renn's introduction to this volume (chapter 1).

remains. It is an interesting question—not to be explored here—what is actually being copied when universities are established on a given model. Is it full-scale copying of every detail, or is it some basic triggers or "stimulations" which then have to be developed locally? If the second, then it is a curious state of affairs that there is so little local influence on the curricula.[2]

The strongest proof of this development is the basic structure of the university: three faculties of the natural sciences, the social sciences and the humanities. It is still the way Francis Bacon conceived the division of what he called the "globus intellectualis" into disciplines. The worst aspect of this development is that there is very little attention being paid to the real core of the university, namely to the curricula being taught. The new universities copy what has already been developed elsewhere, where the "model" universities in America and Europe smugly leave their curricula mostly untouched and concentrate on structural reforms, and on the prevailing budgetary malaise.

There is international awareness of this uniformity of curricula. The Stanford sociologist John W. Meyer and his "school" have commented and documented this worldwide similarity. Their explanation is anti-functionalist and seeking the reason in a general cultural climate which, in their opinion, has become universal.[3]

In an important article (mentioned in the previous footnote), in this mode of argument, Frank and Meyer summarize:

> Our overall argument here is that Modern and post-Modern societies rest on a central conceit […] that the world is a unified and law-like place, comprehensible to everyday persons. Our argument helps explain why the university does not yield to technically superior competition. The university survives and flourishes over recent centuries as the locus of this conceit—the repository of universalized knowledge—not as the training ground for an increasingly complex role system […]. The university's isomorphism worldwide follows from the fact that universities spread in a top-down process—instantiating models institutionalized in world society—not from the bottom-up. And the university succeeds at certifying […] much better than it succeeds in training because training is not the point. The university may be bad in teaching skills, but it is good at re-envisioning local particulars as global universals. (Frank and Meyer 2007, 28)

With all this the authors are quite happy. They find the real proof of their thesis in the fact that:

> […] it is often quite difficult, in examining university catalogues, to find much curricular material that directly indicates just what country, place and period the catalogue is covering […]. Another indicator

[2] On the different types of knowledge transfer in different periods, see many of the other chapters in this volume.

[3] Two publications should be noted: (Frank and Gabler 2006; Frank and Meyer 2007, 19–44).

> of universalism appears in the detailed contents of courses that initially appear to be immediately and obviously role-related. (Frank and Meyer 2007, 30)

The paper, and the book quoted above, are so meticulously researched that I do not doubt the exactness of what is described as the prevailing situation. Indeed, their criticism that most of the research is either about a single discipline, or a single country or even a university, is correct. Very rarely is research on higher education comparative.

My problem lies with the presupposition—the conceit as they call it—that the "world is a unified and law-like place, comprehensible to everyday persons." The world is complex and messy, not at all unified and consisting of and exhibiting universally true phenomena, and it is precisely for this reason that the task of the twenty-first-century university is to prepare the students. All of them—hundreds of millions—are now entering higher education. This does not mean teaching skills—indeed I agree with the relatively low priority of "training"—but it is an epistemological task.

In his Foreword to the Frank and Gabler book (mentioned above), John Meyer talks of "a rather unified university" worldwide, "serving as a kind of church for post-modernity." It is part of Meyer's theory, which permeates this book, that this flat landscape is due to a universal culture, of being a knowledge society, and not a response to any functional needs of societies. As Frank and Gabler put it:

> Most analysts adopt a loosely functionalist point of view, treating changes in the composition of teaching and research (more business, less botany, etc.) as adaptive responses to the shifting needs and interests of either society at large or of its dominant elites. (Frank and Gabler 2006, 7)

They review, and rebut, one-by-one organizational, economic and political forms of functionalism. Their theses are:

> (1) that the university is definitionally committed to mapping reality and (2) that changes in the assumed features of reality thus reconstitute the academic core [...]. By cultural fiat and organizational rule, the university presents reality in objective and universal terms [...]. Violations of the standards of objectivity and universalism disqualify an organization from being a university.

Moreover,

> The huge expansion of the rationalistic social sciences […] provides the needed support for this explosion that Foucault called governmentality. And the relative decline of the humanities helps weaken the alternatives – the senses of the power of tradition, of local particularities, of the gods and spirits, or of natural human desires and needs. (Frank and Gabler 2006, xiv)

> The universalism of the university is what stands out from the global purview. (Frank and Gabler 2006, 199)

The picture given here is precisely what must change. It is a correct description of a "conceit" which in my opinion is normatively wrong, relying on a historical interpretation, presupposing a cultural "flatland" all over the globe, which in my opinion is a fundamentally flawed interpretation.

Lest I be misunderstood, and risking redundancy, I wish to emphasize that I do not want change through the abolishment of teaching disciplines: we need them as a rigorous, methodologically rich foundation for all knowledge, and they must be the basis of undergraduate education from the beginning. The change must come—as we shall see in detail below—by accompanying those introductory, rigorous first-year courses by seminars, given parallel to these, discussing real-life situations, which are almost always interdisciplinary, which do show life as complex, messy and unpredictable, and find their mathematical expression in non-linear equations.

In order to make the redundancy somewhat less vexing, let me formulate the above thesis in a different language: if we distinguish between the body of language and the images of knowledge, which are statements about knowledge, by describing body of knowledge as first-order knowledge, and images of knowledge as second-order knowledge, then the conclusion is: teach introductory courses mainly on the level of first-order knowledge, and the more complex, more sophisticated, albeit, less rigorous courses in terms of second-order knowledge.[4] Several of the chapters in this volume are also couched in this language.

By way of an epistemological caveat, I would like to remind the reader of another concept, which seems to be very relevant here: "Concepts in Flux": in the creative formative stage when a new theory is being formulated by one or several scholars, the questions arises whether the "discoverer," while working on the details of the new theory, is speaking "newspeak" or "oldspeak"; when Einstein formulates his law $E=mc^2$ before having drawn all the consequences that will follow for classical Newtonian mechanics, what language does he think in? During this whole period the new concepts are not yet solidly settled—they are concepts in flux. At this stage the distinction between first-order and second-order thinking becomes blurred. I used this concept and relied on it in my historical analysis

[4] See (Elkana 1981, 1986, 1988).

of the new law of conservation of energy, formulated in 1847 by Hermann von Helmholtz (Elkana 1974).[5] What is needed is a fundamental rethinking of the aims and tasks of the university in the twenty-first century, and the principles or guidelines for constructing curricula that follow from the rethought "aims and tasks." This is the task for very many scholars, university administrators, but even on the policy level of politicians working together, and must be undertaken in all locally different social milieus. I shall come back to the curricular reform below.

But before that comes the challenge to create a general awareness of the acuteness of the problems of the world and the urgency for doing something about them. This is relevant here, because, as a clearly formulated task for the twenty-first-century university, it has not been often formulated. There exist specific research institutes, dedicated to solving well-formulated problems, such, however, that are couched in terms of existing disciplines, with well-known needs for support in manpower, financing and equipment. The most urgent world problems, like hunger, poverty, the spread of infectious diseases, the phenomenon of global warming, the scarcity of water and energy and many others, are distinguished by the fact that no one discipline can cope with them and often the kind of discipline that would be needed does not even exist: in these cases new disciplines have to be created like a new economics, which would integrate classical, mathematical, modelizing main-stream economics with concepts stemming from anthropology, sociology, history, like norms, vales and aspirations.

Similarly for understanding and coping with the spread of infectious diseases like HIV/AIDS, multi-drug-resistant tuberculosis, or malaria, a new discipline is needed which would integrate molecular biology and some of the relevant social sciences. On a different level, and not in the category of burning social problems, but still constituting phenomena for which our inherited theories of political science and sociology do not have the conceptual tools to study, are the phenomena of the spread of moderate religions almost everywhere in the world, and the emergence of new types of regimes which are neither fully totalitarian nor really democratic. To study these, the mentioned disciplines have to be rethought from the foundation. The university is the only social institution which in scope, depth and breadth could possibly be called upon to "invent" new disciplines or rethink old ones: this is indeed one of the unpredicted new tasks for the university of the twenty-first century.

What unites East and West, North and South—that is, world consciousness—is the growing crisis of the physical well being of our earth. The environmental, economic and public health crisis is a causally linked, unintended consequence of the very success of the scientific-technological-economic success of modern times. As Paul Collier pointed out, poverty in some parts of the world is simultaneous with the unprecedented accumulation of riches in other parts of the world (Collier

[5]See also (Elkana 1970a,b). More recently Mara Beller made good use of it in her important book (Beller 1999).

2007). At the same time, the gap between rich and poor in the richest, most successful countries is growing all the time.

Let me elaborate on this demand from the point of view I called previously a need to rethink the Enlightenment. Western capitalistic society gained its success by creating new knowledge in most areas and by accumulating material riches due to a series of values, which for almost two centuries guided thinking and research. These values were formulated during the Enlightenment and became centrally important in the nineteenth century when practical lessons were drawn from what was understood to be the message of the Enlightenment.

The university today, with its research agenda, its service function, its emphasis on social involvement, reflects the cluster of values that were received from the Enlightenment, mainly in the nineteenth century. I emphasize "received" because the great thinkers of the Enlightenment were much richer, broader, more controversial and more pluralistic, than what was received and internalized by the science, the politics, and the philosophy of the nineteenth century. These values are: objectivity, universal validity of theories, realism, rationality, context-independence, abhorrence of contradictions, non-linear thinking, determinism, predictability of the world in all its aspects, a belief in and craving for coherence of ideas and value-systems, anti-dialectical, and especially the newly developed social sciences concentrating only on what was measurable, which resulted in the cultivation of rational choice theories and methodological individualism.[6]

This cluster of values serves as a political guideline to most politicians in most democracies, but also as a cluster of research values to which most scientists/scholars adhere. The presently widespread undergraduate curriculum is based on these values and principles. It is precisely these values and principles which no longer fit the world we live in and the problems that our natural sciences and social sciences have to grapple with, that therefore have to be rethought. It will take an epistemological revolution to get used to thinking in terms of sets of values and concepts which, as Isaiah Berlin has tirelessly emphasized, do not constitute a coherent whole. Values do not ever form a coherent system; we must learn to live with contradictions (as an integral part of our world of knowledge).[7]

We should get used to the fact that all knowledge must be seen in context: not only when looking at its origin, but even when trying to establish its validity and even when looking for its possible application for solving burning problems. A concise way of putting the requirement for an epistemological need for rethinking our world in a metaphorical formulation is "From Local Universalism to Global Contextualism."

One special aspect of global contextualism, to be discussed below, is the integration of parts of local knowledge with the universal general knowledge with which the culture confronts the two. In some areas local knowledge turns out to be extremely efficient, and even of high survival value. It took international agencies

[6] For more on this topic, see (Elkana 2000).

[7] See my paper on rethinking the doctorate (Elkana 2006).

many years until they realized the loss their efforts suffered when neglecting bodies of local knowledge.[8] But let me enlarge a little on this new task for the universities, under the heading "Toward Global Contextualism."

25.2 Toward Global Contextualism

I would like to argue that to a large extent universities are themselves to blame for their failure to respond adequately to the external pressures of the day. Barring the work of a few exceptional departments and individuals here and there, universities are incapable of addressing precisely those problems that most preoccupy our societies today.

Granted, universities rightly regard themselves as playing a key role in preserving intellectual, academic and cultural traditions. This, however, should not be taken to be an acceptable excuse for not dealing with fundamental social injustices and discrepancies—problems often deemed to lie outside the scope of a university's legitimate interests. Since universities are by far the most important institutions in any modern society entrusted with the task of creating knowledge (whether the exclusivity of this knowledge-creating role is a good thing is another question), they should also strive to apply the knowledge created there to major social issues at any given time.

A few examples, some of them already mentioned above, will illustrate my thesis. It would be difficult to find a significant department of economics sponsoring a major research program focused on the nature of the public good, or poverty. As mentioned, there is almost no serious university department that would do research on the problem of combining sociological, anthropological, historical, and psychological knowledge with biology on the molecular level to help us deal with the spread of infectious diseases such as HIV/AIDS, multi-drug-resistant tuberculosis or malaria. Even if the Gates Foundation and others invest huge amounts of money in trying to develop a vaccine against AIDS, unless a new discipline is developed which integrates social sciences with biology at the molecular level, there will be no way to cope with the problem of how these diseases spread in whole societies. Until recently this was the case mainly in Africa, but today more and more countries are witnessing the vicious spread of the diseases.

As a last example, let us take up global warming. Even though by now there is almost universal consensus about the fact of global warming, we do not have the sought-after intellectual answers—beyond the political/economic—to this crisis, to the extent that leading experts disagree not only on possible solutions, but also on whether the catastrophe will take place in two years or two hundred years. The reason for this is partly political and partly epistemological, but both are rooted in the way we teach at our universities. The political: neither the scientists, nor the politicians are willing to admit publicly that science has no answer to this question.

[8] Part 3 of the present volume, especially the survey chapter 16, is an important reminder of this issue.

The problem is quasi technical: the number of parameters that one would have to consider for a credible prediction is so enormous that even with our modern computers, it would take ages to complete the calculations. Therefore the model-building scientists must make a choice of the parameters taken into account—each choice renders a different prediction, and these diverge widely. The epistemological is the fact that the phenomenon is a typical non-linear one: there are no linear equations, no solvable differential equations that would yield acceptable results. And our undergraduate curriculum—at least in most universities—does not involve teaching non-linear phenomena, or what is called, somewhat simplistically, non-linear thinking. This will come in naturally in those first and second-year seminars dedicated to real-life situations of an interdisciplinary nature, that we recommend here to be taught parallel to the introductory courses—rigorous and basic—which describe a predictable, easy-to-understand, “linear” world.

Paradoxically, by stretching the university’s functions and capacities to breaking point and by blurring its identity, globalization created the exact opposite of what we should expect of places of learning and scholarship today. To repeat: what we need is to move away in our teaching—and thus also in our thinking—from local universalism and work toward global contextualism.

In a nutshell, global contextualism is the idea that, whatever the academic discipline, every single universal or seemingly context-independent theory or idea rooted in the tradition of the Enlightenment should be rethought and reconsidered in every political or geographical context, different from the world as it used to be in the Age of Enlightenment in Europe, and in the nineteenth and twentieth centuries, also in America.

Global contextualism is one of the most important developments in world history since the Enlightenment and universities are uniquely placed to help us to understand it and to promote its growth. All the more regrettable that practically no university raises serious questions concerning the old structures which were then the relevant context for the disciplines as they were introduced.

Although it is hard to do justice to the complex issues of contextualism here, it is clear that to raise a question about context is first and foremost to raise a question about meaning. But it is precisely meaning—with all its flexibility, plasticity, ambiguities, and contradictions—that is neglected by universities for both systemic and intellectual reasons, and to which reasons I now turn. These reasons can probably be subsumed under the problem of academic freedom as it is understood today, and as it should be reinterpreted so as to fit the twenty-first century.

25.3 Academic Freedom

Academic freedom is severely limited for students, graduate students and scholars in the early stages of their career until, with tenure, they gain the freedom to research what they want. What results from the way an academic career is currently structured is that young people are thrown into a groove that they can never leave if they ever want to remain successful in academe.

Let me again offer some examples. Consider, first, what is happening in economics departments. As mentioned above, the real challenge is to create an integrated discipline, a new body of economic theory, bringing together traditional interests of economists couched in advanced mathematical terms with a novel emphasis on norms, aspirations, values, and social ideals. Such a unified theory is a must if economics is to remain pertinent to today's needs and problems. Mainstream economics refuses even to consider this need: a combination of vested interest in the existing theory, of gatekeeper mentality, which is especially strong in economics, and the fact that economists are highly paid as consultants and experts—remained seemingly uninfluenced by the unpredicted and under-explained global financial crisis. Mainstream economic theory is wed to the idea that markets will revert to equilibrium when left alone—though the opposite seems to be the case. Serious economists, and financiers like George Soros, who have amply proven that they understand the crisis, its causes and its possible remedies much better than the great mainstream economists—some of them Nobel-Prize winners—have repeatedly pointed this out. Indeed there are some few attempts to found departments for the "new economics": Columbia University, Oxford University, Cambridge University, the Central European University in Budapest are all supported by George Soros. For us the relevant point is that young economists who would like to explore new ground are strongly discouraged by their departments and by the leading mainstream economists, and it is made clear to them that if they do not follow the guideline their career is in danger. This applies even to more limited and less daring new directions like behavioral economics. But these new departments can become effective only if they do not only house a few, rebelling Nobel-Prize winners, but create new positions in a critical mass for young scholars whose careers will not be endangered by pressure from the mainstream.

Similarly, this is the case in departments of cognitive/experimental psychology: positivistic, reductionist approaches, no emphasis on context or meaning, and almost obsessive preoccupation with rational choice theory. And the same is happening in departments of political science. The rigid intellectual groove in which aspiring young academics move is fixed a priori.

Unfortunately the granting agencies and funding institutions and foundations follow the same pattern. But even more importantly, there is once more the epistemological consideration: mainstream economics does not study context—and therefore meaning—thus these are not central concepts in economic theory. The same holds for the other academic departments mentioned above. In the framework of the sweeping reforms advocated here, we must now turn to psychology and the theory of meaning.

25.4 Psychology and the Theory of Meaning

Jerome Bruner has convincingly argued on a number of occasions that psychology, cognitive science and other related disciplines systematically neglect meaning and ignore the fact that meaning is socially constructed. This failure is not just a coincidence or a fluke. It is perpetuated by well-entrenched systemic failures, incentives, or even expresses institutional prohibitions.

As a result, not only is the academic career of young scholars being influenced, but very often graduate students are not allowed to carry out research in other than mainstream areas, based on a paradigm different from the established and accepted one. Graduate students are not given the place, the infrastructure, the incentives and general wherewithal to do and publish innovative work on meaning. To be fair, this situation has changed somewhat owing in no small measure to Bruner's pioneering work on "narrative." It was Bruner's strategic decision to concentrate on the theory of narrative—borrowing much from literary theory—proposing the thesis that via a study of narrative in different disciplines, a study of meaning will be reintroduced. As a result, narrative was introduced into the curriculum of Columbia Law School where Bruner had been teaching for more than ten years.

Interestingly, this development has been paralleled, also at Columbia, by introducing "narrative medicine" into the medical school. These are laudable attempts to break with earlier practices to exclude the study of meaning from teaching and research at psychology and cognitive science departments, but they are not sufficient on their own.

In a way, more broadly than the need to study "meaning," there is a good case to be made that the exclusion of semantics (in the contextualized sense, not formal semantics) in many linguistics departments is largely due to the exclusive preoccupation and thus success of the Chomskyan syntax-centered research program. Although the criticism of this approach is growing rapidly,[9] the very absence of a well-formulated alternative theory that can be presented to students as a coherent whole contributes to the persistence of the present state of affairs. I should make it clear, however, that I do not advocate here a return to the pre-Chomskyan era. Nor do I wish to underplay the enormous achievements of Chomskyan linguistics. Having said that, it is imperative that we develop in the universities areas beyond what has been achieved so far. In particular, comparative and historical studies of languages should be reintroduced. This is a considerable challenge, but it has to be tackled, and be tackled by the universities themselves.

When returning to historical and comparative linguistics, which had been neglected for some time under the influence of the Chomsky dogma, those universal characteristics of language that Chomsky had discovered must be taken into account, and the differentiae should be studied comparatively and historically beyond the universals.

[9]See the work of Guy Deutscher of the University of Manchester, or of Nicholas Evans and Stephen Levinson (2009).

Also the Sapir-Whorf hypothesis has to be reviewed taking the post-Chomsky findings into account. But beyond that, comparatively and historically one must study those elements of language which influence formatively the social and cultural differences between people—that is, languages.

The hypothesis developed by Edward Sapir and Benjamin Lee Whorf consists of two principles: (a) linguistic determinism, i.e. the principle that asserts that language determines the way we think, and (b) linguistic relativity, i.e. the principle that states that those that speak different languages conceive of the world differently. Chomsky and his followers, promoting a universal grammar—that is syntax—rejected the Sapir-Whorf hypothesis, and neglected a comparative, historical study of languages which could have thrown light on this complicated and important question. If we now reintroduce comparative-historical linguistics, based however on the achievements of Chomskyan theory, we shall be able to study anew issues of meaning, translation, and cultural contexts.

Daniel Dor's theory of language as a socially-constructed communication technology is a new and ambitious attempt to walk in this direction: It rethinks the universality of language in social-functional (rather than cognitive) terms, positions social meaning (and its relationship with private, experiential meaning) at the center of the theory, and allows for a new interpretation of the Sapir-Whorf hypothesis (Dor and Jablonka 2010).

Cassirer's work on language, myth and science is of great help here, even though his formulations are outmoded and must be reformulated to fit the state of the art of our times. Similarly Fritz Mauthner's major work (1901)[10] and even the pioneering early work of Otto Jespersen[11] are again becoming relevant.

Another important example is the ongoing struggle at many universities to separate the study of sociology fromanthropology: "Sociology is about us, anthropology is about them." This is another old-fashioned distinction that needs to go.

These antiquated curricular practices are paralleled by the design of the grant system for funding academic research. Foundations, as already mentioned, often attune themselves to the research agenda and institutional organization of the universities. This is an unholy alliance that severely limits the academic freedom of the research community. In many countries, leading research foundations talk about embracing interdisciplinarity as an important priority. At the same time, they encounter enormous difficulties in evaluating truly interdisciplinary research. These are, I am wholly aware, controversial claims. But what I am proposing here are fundamental mutations in the institutional framework of academic research and urgently need to be addressed.

Discussions on curricula and institutional design often tend to concentrate exclusively on elite universities—that is, the great research universities of the United States and the handful of leading universities in Europe. However, this focus on a

[10] Mauthner was an Austrian linguist and a student of Ernst Mach.

[11] Jespersen's works appeared from 1889 onward; he was a famous Danish linguist, specializing in English grammar. See, for example, (Jespersen 1889, 1894).

few outstanding institutions can easily mislead those thinking about the future of academic research and higher education.

We have so far—I believe correctly—discussed only epistemological issues, mainly contents and curricula. But needless to say, these are intricately involved with structural matters in the way academe is organized. Only in America and in Europe are there around one million faculty members who earn a living by teaching at universities, but who in fact publish research papers.

Witness the growing pressure to produce publications. This by now has become a sine qua non of academic success, indeed even of mere survival in academe. But it is perhaps the most important limitation on genuine academic freedom, a constraint that is all the more regrettable as all practicing academics are familiar with the inferior quality of arguably as much as 80–85% of published output. Universities in very many countries are places with overcrowded auditoria, overworked professors who teach not more than six to nine hours a week, who are pressured to spend every precious moment on research, have very little time to spend with the students or indulge in dialogues in small groups, participate in numerous committees and write grant proposals. Most of the teaching is in form of frontal lectures imparting information, which today is easily available on the internet. All this shows that the way universities are structured does not fit either the multiversities with tens and even hundreds of thousands of students, nor recent developments in the availability of information, and preaching principles which were fitting for very small elite groups dedicated to the creation of new knowledge by way of research, where the interaction between professors and students was almost one-to-one. This was the case in the early nineteenth-century German university, and in the American research universities emerging at the end of the nineteenth century, well-suited to small elite universities and small groups of outstanding researchers. It is only in the case of this select group that the teacher and the researcher must be one. Yet this requirement has by now spread to the huge "multiversities": every faculty member has to be a researcher and, what is worse, author of an unending outpouring of publications.

As a matter of university policy, it would be worth investigating whether these two activities could be separated. The basic idea would be to offer different streams: (a) faculty (not more than 3-5% of the professors) whose lifestyle and abilities fit a more or less full-time research career, who work closely with the 3–5% of students, who by degree of curiosity, temper and ability will lead a life of advanced scholarship and research; to those who are going to combine teaching and research; (b) the rest of the faculty (in much smaller numbers than today), who will do the kind of research needed for good teaching, will be free from any publication pressure and will teach for sixteen to eighteen hours a week.

Not as lip-service, but by genuine conviction society has to learn to respect those faculty members, who by temper and talent can and want to dedicate most of their life to teaching. These are not less gifted or less intelligent members of the faculty than the full-time researchers, but individuals with different priorities and temperament. They are not, nor should be treated or considered, as second-class citizens. They should have the same salaries, promotion conditions and enjoy the same academic “perks” as the researchers.

Actually this would amount to a new social contract between politics, society and the university administrations, faculty and students. This change is inescapable if the university is to become less expensive and at the same time not qualitatively worse, considering the fact that no government, especially in the welfare countries, will be able to spend for higher education what it needs to keep up the level of its present structure.

Against the background of this, now is the time to return to the principles for a new undergraduate curriculum.

25.5 Redesigning Undergraduate Curricula

In order to cope with the problems sketched above, we must concentrate on developing a new kind of undergraduate curriculum that responds to basic demands for the twenty-first century. These demands require our proposals to be clustered around the following three challenges: genuine interdisciplinarity, the education of concerned citizens, and the fostering of nonlinear thought. I will address each one of these.

One cannot emphasize enough that we should not abandon teaching disciplines; it would lead to the loss of intellectual responsibility. However, it is time we took note of the fact that a young person, after completing three or four years of university studies, will typically face problems “out there” that are interdisciplinary in nature. This is irrespective of whether he or she goes on to do research, joins an NGO, goes into politics, or chooses some other profession.

When a problem is interdisciplinary in this sense, no existing discipline on its own will be able to provide the intellectual tools to deal with it. But how can young people be trained for such a situation? Higher education today lacks the resources, both institutionally and intellectually speaking, to prepare young graduates for these real life situations posed by the exigencies of their profession or research.

Even when universities, research centers, or funding organizations do take on board the notion of interdisciplinarity, they usually commit what we can call the “interdisciplinary fallacy.” We see this fallacy at work when donors or university administrators act on the mistaken assumption that to solve a problem that goes beyond the scope of any given discipline, one merely has to convene representatives of various disciplines and “put them in a room” for a solution to emerge. What is fundamentally wrong with this approach is the failure to recognize that ten different mindsets sitting together will not come to much. Instead, we need scholars who in addition to knowing their own disciplines are capable of a genuinely interdisciplinary way of thinking.

In order to acquire this interdisciplinary way of thinking, rigorous and stimulating training is required from the early undergraduate level. I do not have the space here to describe in detail how such training ought to be designed, but I can offer a few examples. First, as already noted, in order to train a person to think in terms of disciplinary paradigms as well as beyond the limits of the disciplines, we will need to begin with first-year students and not with advanced students already seeking a doctoral degree. It is too late for someone writing a doctoral dissertation in physics to discover that, for example, quantum theory and the theory of relativity conflict conceptually in a most fundamental way.

It was for this reason that we proposed above to teach, in parallel, basic introductory undergraduate courses (in science, or economics, or in any other discipline) and seminars that will expose students to conceptual inconsistencies, to phenomena or situations where the basic theory does not work, or even to the basic incoherence or incompleteness of the basic theories as such. Such seminars would bring into focus the "real-life" situation. In an ideal world, one and the same professor would teach these parallel courses in the given discipline, although anybody familiar with higher education, and not naïve, knows that this suggestion would be hard to put into practice.

Our century-old resistance to such ideas stems from preconceptions concerning the needs of children and young people. Particularly popular and of detrimental influence has been the thought that what an aspiring and gifted young person really needs is intellectual certainty. What a young person really needs is emotional certainty, not intellectual certainty! Overseeing this basic truth has been responsible for the overwhelming ambition of most authors of university curricula not to expose young people to contradictory or conflicting ideas. This is an absurdity. Highlighting and even embracing contradictions is the right, and possibly, the only way to cope with the complexity and messiness of the world, and should in my view be a key element of higher education from the first-year level on.

The second fundamental objective in redesigning curricula is to foster the education of what I call concerned citizens. The term "concerned citizen," as we shall analyze below, carries moral implications too. I am not so much concerned here with the ethical dimension, but rather with the underlying cognitive and intellectual content of this term.

Quite simply, educating concerned citizens is to educate young people—all of them—to understand the main problems of the world; one encounters these on the pages of any good daily newspaper. Why is it, we may want to ask, that we have so little understanding of how to fight poverty and how to help the "bottom billion" (to use Paul Collier's term)? Why is it that we do not know how to come to grips with the medical, social and economic problems of worldwide epidemics? Problem-oriented thinking focusing on such issues must be introduced as early as the undergraduate level.

The concept of a "concerned citizen" has two dimensions: a moral/social and a cognitive. The moral/social is very often invoked: for example, a recent publication of LEAP (2007) (Liberal Education & America's Promise), called "College Learning for the New Global Century," formulates it as "Personal and Social Responsibility." This involves civic values and engagement, knowledge of the major social problems that plague the world and the fundamentals for social/political activism. At the same time university is not supposed to deal directly with political issues, and the teaching should not be politicized. Social skills are also subsumed here. One could also mention under this heading education for democracy—I deal with this in a special chapter of my forthcoming book because of its importance (Elkana, forthcoming).

On the other hand the cognitive dimension of being a concerned citizen is very rarely mentioned. By this I mean a training of young people which, after three or four years of undergraduate studies, should enable them to understand the major social problems of the world, what is being done to deal with them, what is not being done, and above all, what the epistemological gap is that prevents them from being dealt with. This last point is of greatest importance because it is not usually taught how to understand the limits of disciplines in order to deal with the problems. The tendency is to ascribe the lack of preoccupation with these issues exclusively to corruption, political interference and other such factors, as much as they are important and prevalent.

It was discussed above that the task of universities is to encourage the emergence of new disciplines and the rethinking of some of the older ones. The most glaring examples have already been mentioned, such as fighting poverty, the spread of infectious diseases, the issue of global warming.

Appended to this article is a Manifesto which in eleven bullet points outlines the principles for constructing undergraduate curricula. The background idea is that in order to consider contexts of various kinds—social, cultural, religious, disciplinary—different curricula have to be prepared for students who intend to go into research, teaching, the professions, business and so forth. Yet at the same time there are principles that should apply to all. The curriculum research that follows will then concentrate in translating the principles into the different specific curricula. Also in the appended Manifesto, point (4) says:

> Use these challenges to demonstrate and rigorously practice interdisciplinarity avoiding the dangers of interdisciplinary dilettantism.

It seems so obvious that it is perhaps superfluous to make a point of it. Yet, it so often happens that when tackling a problem which spans many disciplines, it is forgotten that the relevant disciplines must be brought together in the most rigorous fashion, especially since it is expected that every participant in the work for the solution of an interdisciplinary problem is supposed to be a master of one or two disciplines, while being aware in a much more superficial way of the other disciplines relevant for the work they are doing. For an expert in one or two disciplines it is very daunting to remember that the other disciplines of which he/

she is not a master, but has superficial ideas about, must be as rigorously treated as the ones he or she is master of.

Finally, we need to understand and draw practical conclusions from the fact that almost all of these major problems society faces today are what can be termed colloquially nonlinear in terms of the mode of thinking and method they require. That is to say, they are non-predictable, nondeterministic and often resist reduction toward one, universal general theory. They are much more complex and ambiguous and rich in contradictions. This point is worth elaborating on in some greater detail.

The curriculum should make students in all areas acquainted with the principles of non-linear thinking or, in the words of George Cowan, founding director of the Santa Fe Institute for the Study of Complexity, introduce them to "the sciences of the twenty-first century."

As a caveat, it should be mentioned that all of these "new" sciences and "new" concepts like non-linear dynamics, chaos, complexity, network theories, actually emerged, sometimes even in the very same terms, at the end of the nineteenth century in works of scientists like Poincaré, Boltzmann, Gibbs, and later Shannon and von Neumann. What is definitely new is the scope of their spread and relevance, and the successful attempt to show that the concepts and the mathematical formulations that involve them are identical for a broad array of disciplines in the natural, as well as in the social sciences. It brings back a new kind of "unity" of knowledge describing, however, a messy, complex, unpredictable, indeterministic world.

The presuppositions underlying such a course (or courses, or seminars, or discussion groups), repeating what was said above, are as follows: it is important at an early stage, parallel to rigorous introductory courses of basic science, to show where these rigorous, classical theories fail to explain phenomena and to give the best possible introductory course—non-rigorous as it may turn out—of interesting real-life phenomena which are not covered by the basic courses and for which the students are definitely technically not ready. However, socially, morally and in the extent of their curiosity, they are more than ready.

Introductory courses in the sciences and the social sciences are rigorous, systematic, reductionist, positivist and linear in mode, describing only the regular side of nature or society, of the economy or of the mind. Disorders in the atmosphere, turbulence in the clouds or in the sea, fluctuations in populations, oscillations in the brain or in the heart, non-equilibrium state of the economy, and most other phenomena known from daily life, are irregular phenomena, what is often called non-linear, and classical science or social science has no tools to deal with them.

It is here that a host of new emphases in knowledge become relevant: chaos, complexity, non-linear dynamics, emergence as a general phenomenon in nature or in society. A host of new concepts, indispensable for studying irregular phenomena, like attractors, fractals, bifurcations, nodes, hubs and many others have to be understood. They must become part of the basic literacy of every citizen of the twenty-first century, irrespective of whether they will be professionally preoccupied with these concepts or areas of research.

It is my understanding of an undergraduate curriculum—or rather of undergraduate curricula—that an introductory course on such matters in the first or the year year has to be taught to all undergraduates, irrespective of whether they will continue in research, in the professions, in the economic/financial sector or in any of the services, or become teachers in elementary or secondary schools, or in community colleges.

To exemplify what I am suggesting, let me mention a few books which could be used in such courses. These are all well-written, introductory—not to say popular—books:

1. James Gleick: *Chaos*, Heinemann, 1988
2. M. Mitchell Waldrop: *Complexity*, Touchstone, 1993
3. Albert-Laszlo Barabasi: *Linked*, A Plume Book, 2003
4. Edward N. Lorenz: *The Essence of Chaos*, UCL Press, 1995
5. Philip Ball: *Critical Mass*, Arrow Books, 2005.

I am sure there are many other books, some even more recent than these, but a look at these will serve to make my arguments clear.

Much of classical science was built on the presupposition that systems can be understood in terms of their constituent parts; systems could be broken down to those ingredients and could be built up again from them. The idea was that the whole could be built up from the parts, and that the whole was neither more nor less than the sum of the parts. In the natural sciences this meant analyzing all kinds of bodies into atoms, nuclei, electrons, and in later developments, into quarks; live systems into chromosomes, genes, neurons. The processes of breaking down to constituent parts, or in building up the whole, was pure reductionism with no place for randomness. The eighteenth-century dream (Laplace and others) of deterministic probability no longer applies.

In a different formulation it could be said: Relativity Theory applies to the very large (way out of the human scale), like galaxies and universes; Quantum Mechanics applies to the very small (way below the human scale), like subatomic particles, while chaos theory, complexity theory (if they can be legitimately called "theories"), deal with objects on the human scale, what real life confronts us with. "Emergence" as a much-studied phenomenon in the life sciences, but also in phenomena that describe process in the physical world, is the prime example for phenomena where the sum is definitely more than just the sum of its parts. Time direction becomes a central concept to be taught at a very early stage, parallel with the Newtonian worldview, even if first introduced more on the intuitive than on the mathematically appropriate technical level.

Classical science viewed the natural world in terms of the second law of thermodynamics according to which all nature aims at ideal disorder; life—which is the most important phenomenon of order—remained unexplained in terms of classical, Newtonian/Laplacian theory. Classical economic theory—mathematically sophisticated as it may be—deals with a world where the market aims at, and will reach, perfect equilibrium. But the market usually does not approximate equilibrium, as the recent financial crisis has taught us in a bitter lesson. (These examples can be skipped by those readers who are not keen on going into more detail at this stage.)

25.6 A New Introductory Seminar

In what follows I will try to illustrate, albeit superficially, what could be part of such an introductory seminar or discussion group, relying on what was stated above. An obvious beginning would be the so-called "butterfly effect" (also called "sensitive dependence on initial conditions"). Unlike what is presupposed in classical science, small differences in the initial conditions can make enormous differences in all those cases where deterministic numerical forecasting does not hold. Newtonian determinism seemingly works quite well for distant, huge, celestial objects. The closer we get to our daily experiences in life, the less deterministic our forecasting becomes: for stars and comets it works, for clouds and winds it does not. As an early researcher on chaos formulated: "Any physical system that behaved nonperiodically would be unpredictable" (Gleick 1988, 18).

In all model-making disciplines like biology or economics or politics, what usually happens is that if the model predicts absurd situations, the programmers revise the equations to fit the output to the expectations. Especially economic forecasts were blind to what the future would bring while the politicians, for want of anything better, tend to act on those predictions.

Complex behavior is described by non-linear equations:

> [...] they were non-linear, meaning that they expressed relationships that were not strictly proportional. Linear relations can be captured with a straight line on a graph [...]. Linear equations are solvable, which makes them suitable for textbooks. (Gleick 1988, 23)

In one of the formulations: in linear systems the whole is precisely equal to the sum of its parts. When the whole amounts to much more than the sum of its parts—most nature is like that—the mathematical expression of this state is in non-linear equations (one whose graph is not a straight line but some kind of curve). (One could study the narrative of the Los Alamos Center for Nonlinear Systems.)

Phil Anderson's classic paper could be an important source for discussion (Anderson 1972). Probably the strongest statement against reductionism with its claim that the idea of all physical laws, in the final account, can be reduced to one basic law. Raising the question: "how do we know that not all different levels of organization have different fundamental laws, not reducible to each other?" opened up totally new approaches to nature and life.

Stuart Kauffmann's latest book against reductionism might serve as recommended reading (Kauffmann 2008). His previous books (still imbued by a reductionist spirit), about life, the nature of complexity and self-organizing systems might be too technical for this kind of course (Kauffmann 1993, 1995).

The issue of "emergence" with examples from biology and physical systems is important to be studied in an introductory course like this, even if at a non-rigorous level.

Processes where the rules are changing during the process are described by non-linear equations. For example: friction depends on the speed, and vice versa.

Examples should be brought from fluid dynamics and the central equation of this domain, the non-linear Navier-Stokes equation should be explained as far as possible.

A typical course in classical physics will introduce oscillators. Non-linear oscillators are rarely mentioned at all. In such an introductory course they should not be omitted.

Students learn to solve differential equations "that represent reality as a continuum changing smoothly form place to place and from time to time" as one expert has formulated. It is rarely taught to students that most differential equations cannot be solved at all.

Non-technical, low-level explanations should follow the work of Benoit Mandelbrot and his fractals, and also the work of Bourbaki following the intuitions of Poincaré.

Turbulence: to be explained conceptually with as little mathematics as possible at this early stage of studies.

Phase transitions: liquid to gas; unmagnetized to magnetized. To be explained conceptually with as little mathematics as possible at this early stage.

Attractors: definition in an easy, understandable way for beginners; examples for attractors be it a point or a series of points or a line or whatever.

If at all possible, one should find a way to explain to first-year students the concepts of renormalization, scaling, ways to deal with non-linear equations, and so on.

The different definitions of complexity and of self-organization as they occur in the different disciplines should be mentioned, explaining the reasons why different disciplines use different definitions.

An extended narrative of classical vs. new economics—from Adam Smith and Keynes and Schumpeter to Brian Arthur, Joseph Stiglitz, Amartya Sen, Edmund Phelps. Discussion of the basic dogma of the stability of the marketplace and the market's unstoppable aim toward equilibrium, as against its apparent failure. One should not omit the introduction of positive feedback and Brian Arthur's theory of "increasing returns." Also mention should be made of the similarity between biological systems and the market through the concept of self-organization.

Brian Arthur's classic paper in *Scientific American* "Positive Feedback in the Economy" should be read by the students (Arthur 1989).

The narrative of the founding and functioning of the Santa Fe Institute.

Networks: how networks emerge, what they look like and how they evolve. Make the student realize that networks are present everywhere: nature, society, business and so forth.

A good introduction could be the story of Euler and the Koenigsberg bridges, as told by Barabási (2003, 9–13). This would already introduce the concepts of 'graph,' 'node,' 'link,' and 'network.'

The difference between random networks and the search for organizing principles of networks to be introduced with examples from as many different disciplines as possible.

Introduce the concept of 'six degrees of separation' and use Duncan Watts's book *Six Degrees* (Watts 2004).

In sociology, the students could be introduced to Mark Granovetter's classic paper: "The Strength of Weak Ties" (Granovetter 1973). This will already show that society is structured into highly connected clusters—it is far from a random universe. Self-organization and nature's urge to synchronize can be explained here with numerous examples.

The concepts of 'connector' and 'hub' may be introduced. The presence of connectors (nodes with an anomalously large number of links) shown to be present in all complex systems—economic, biological, social. In the World Wide Web, highly connected nodes are called 'hubs.'

Introduce and explain with many examples the 'bell-shaped curve' (Gaussian distribution), the 'power law,' the 'scale' and 'scale-free' distributions.

Clearly these were a random collection of points to be included in the preparation of a course on non-linear thinking. It would need the expertise of the best scholars working in these areas to tell us how to make them into a coherent whole of an introductory, non-technical chapter to be used for students of the natural and social sciences as well for students of the humanities. The important point is to realize that such a thinking is a fundamental ingredient of any person's intellectual repertoire if he or she is to get an understanding of our "complex and messy" world.

The greatest obstacle to adopting the approach advocated here is the arguable worry of many scholars that introducing all these important concepts and theories on a superficial level will result in cultivating half-baked ideas. The answer here is that if such "sources" are given parallel to the rigorous, technically sophisticated introductory courses, which however do not apply to most real-life situations, the balance between being serious and scholarly and being popular, relevant and urgent is addressed. On the even more positive side, students' curiosity about real-life situations with which most of them enter university will be satisfied instead of postponed to graduate studies—a time by which many of the students will have dropped out—intellectually or physically—frustrated by irrelevance and boredom.

As mentioned, I will append to this article the text of a Manifesto on "Principles for Rethinking Undergraduate Curricula for the 21st Century" that were developed by a group of scholars convening at the Wissenschaftskolleg zu Berlin in the academic year 2009/10 and which is now available on the Web, inviting widespread discussion.[12]

25.7 Curriculum Research and the Future of Higher Education

I will conclude by saying a few words about curriculum research. The notion of curriculum research is almost entirely unknown in most of continental Europe (or in Israel for that matter; notable exceptions are the Scandinavian countries and the Netherlands). It is typically confused with didactics. The United States and Great Britain are among the very few countries where serious attention is paid to curriculum research.

Curriculum research involves the epistemologically oriented study of the foundations of areas, disciplines, or clusters of disciplines, and the utilization of the results and findings of high-level research in teaching and the design of research programs. Without a serious commitment to curriculum research—a complex undertaking involving the concentrated effort of several teams over many years—no university reform can be successful.

The short-term prospects for such an intellectual enterprise are not optimistic. In the wake of the financial crisis, "the gatekeepers" are becoming stronger and stronger and more and more resistant to the idea of change. Therefore universities, by nature conservative, are unlikely to become easily partners for curriculum research and curriculum reform. On the other hand, one encounters in more and more universities and research groups brilliant young scholars who are socially aware, dissatisfied with the pace of change in their institutions, and ready to invest time and energy bringing about the desired changes. Financial support has to come from the outside: from independent foundations, strategic alliances with stakeholders in the private sector, intergovernmental research organizations, and more. At a later stage, the novel curricula will have to be tested at willing universities. Moreover, constructing a new curriculum has to be undertaken by a critical mass of scholars who will work hard preparing such a new type of curriculum and then be ready, each one of them, to teach what the curriculum needs and to give up the privilege, couched in terms of academic freedom, according to which each professor teaches what he/she feels like teaching. It may look superficially like an infringement of their academic freedom—that is why it must be done voluntarily and not top-down. Yet obviously the commitment of university administrations on the level of President, Rector/Provost, Deans and Heads of Departments is a must. This, I believe, is a formidable but worthwhile challenge for the years to come.

Let me end on an optimistic but, I hope, not irrationally optimistic note. Many of the problems I have outlined emerged because many of the "good" young people have tended not to go into politics or into academe for the last thirty

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[12] See http://curriculumreform.org.

years, but preferred to make money. As a result, the world of academe has fewer doctoral students and gifted researchers and politics has very few genuine leaders and change-makers. Talent has preferred making money on Wall Street or in law firms instead. According to some recent estimates, as many as 60% of the most talented graduates have gone to Wall Street during the last few years. Seemingly and hopefully this bubble has burst.

And another optimistic thought: For the last decade, many thought wrongly that globalization would abolish the nation state and create a kind of cultural flatland using bad English. This has turned out to have been wrong.

Once again, we see national governments and national institutions acquiring new strength in the wake of the global economic and financial crisis. At the same time, the increasing influence of governments will predictably lead to a strengthening of the party system. As a result, many gifted young people who now have nowhere to go will once again choose academe and politics. This may well become the trend dominating the higher education sector in the coming years.

We have some reason to hope that the growing significance and intensity of political life will attract better people, who in turn will turn to the universities again for intellectual ammunition and knowledge better suited to handling today's problems. That could provide new incentives to change the university system and put pressure on the political domain to seriously engage with science, research and universities in a dialogue of equals. If the diagnosis I have sketched does justice to the facts on the ground, then such new incentives and such encouragement will be sorely needed for a brighter future in higher education.

25.8 Appendix: Principles for Rethinking Undergraduate Curricula for the 21st Century, *A Manifesto*

The current crisis of the university is intellectual. It is a crisis of purpose, focus and content, rooted in fundamental confusion about all three. As a consequence, curricula are largely separate from research, subjects are taught in disciplinary isolation, knowledge is conflated with information and is more often than not presented as static rather than dynamic. Furthermore, universities are largely reactive rather than providing clear forward-looking visions and critical perspectives. The crisis is all the more visible today, as the pace of social, intellectual and technological change inside and outside the universities is increasingly out of step. While universities worldwide are undergoing many, often radical, structural transformations, ranging from the Bologna Process in Europe and the Excellence Initiative (*Exzellenzinitiative*) in Germany to the rapid expansion of universities in India and China, the accelerating decline of public investments in universities in the United States and elsewhere and an ever growing demand for university access everywhere, much less attention has been paid to university curricula. But for the university as a community of scholars and students, that is its central function and the key to its internal renewal. Universities are embedded in multiple institutional, economic, financial, political and research networks. All of these generate pressures and constraints as well as opportunities. The curriculum, however, is the core domain of the university itself.

Here we present a set of eleven overlapping principles designed to inform an international dialogue and to guide an experimental process of redesigning university undergraduate curricula worldwide. There can be no standard formula for implementation of these principles given the huge diversity of institutional structures and cultural differences amongst universities but these principles, we believe, provide the foundational concepts for what needs to be done.

1. As a central guideline teach disciplines rigorously in introductory courses together with a set of parallel seminars devoted to complex real life problems that transcend disciplinary boundaries.
2. Teach knowledge in its social, cultural and political contexts. Teach not just the factual subject matter, but highlight the challenges, open questions and uncertainties of each discipline.
3. Create awareness of the great problems humanity is facing (hunger, poverty, public health, sustainability, climate change, water resources, security and so forth) and show that no single discipline can adequately address any of them.
4. Use these challenges to demonstrate and rigorously practice interdisciplinarity, avoiding the dangers of interdisciplinary dilettantism.
5. Treat knowledge historically and examine critically how it is generated, acquired, and used. Emphasize that different cultures have their own traditions and different ways of knowing. Do not treat knowledge as static and embedded in a fixed canon.
6. Provide all students with a fundamental understanding of the basics of the natural and the social sciences, and the humanities. Emphasize and illustrate the connections between these traditions of knowledge.
7. Engage with the world's complexity and messiness. This applies to the sciences as much as to the social, political and cultural dimensions of the world. This will contribute to the education of concerned citizens.
8. Emphasize a broad and inclusive evolutionary mode of thinking in all areas of the curriculum.
9. Familiarize students with non-linear phenomena in all areas of knowledge.
10. Fuse theory and analytic rigor with practice and the application of knowledge to real-world problems.
11. Rethink the implications of modern communication and information technologies for education and the architecture of the university.

Curricular changes of this magnitude and significance both require and produce changes in the structural arrangements and institutional profiles of universities. This is true for matters of governance, leadership, and finance as well as for systems of institutional rewards, assessment, and incentives; it is bound to have implications for the recruitment and evaluation of both professors and students as well as for the allocation of resources and the institutional practice of accountability. The experimental process of curriculum reform we hope to stimulate by offering these guiding principles will thus require the collaboration of scholars and educators willing to transform their scholarly and educational practices and of administrators willing to support experimentation and to provide the necessary structural conditions for it to succeed.

These principles are the conclusion of deliberations by a working group of scholars that met at the Wissenschaftskolleg zu Berlin during the academic year 2009/10. Some were fellows at the Kolleg, others joined the group because of their interest in these issues. The Wissenschaftskolleg supported the work of its fellows. In addition, these principles have already been adopted by a first group of institutions as a blueprint for local curriculum reform. The group involved in drafting these principles represented diverse disciplines (from the natural and social sciences to the humanities), geographical origins (Europe, North America, and India) as well as career stages (from former university presidents to students). They invite their colleagues around the world to join in this effort of re-thinking and re-shaping teaching and learning for the university of the future.

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Chapter 26
The Soviet Psychologists and the Path to International Psychology

Ludmila Hyman

26.1 Introduction

Psychology today is undergoing a transformation. It is becoming an international science, which aspires to uncover universal laws of human behavior and cognition as well as to account for their cultural variation. How can we understand the transformation of concepts, ideas, and approaches involved in this process? In this chapter, I examine a historical precedent for the globalization of psychology. In the 1920s–1930s, a group of Soviet researchers led by L.S. Vygotsky proposed a new kind of scientific psychology that would be international in scope. It was revolutionary in its assumption that the study of mind and behavior, in phylo- and ontogenesis, had to be grounded in the study of the cultural and material conditions in which people live. Although this research program as such largely failed, the Soviet psychologists contributed much of value, and their ideas were taken up—and transformed—by Western psychologists. These ideas form the basis of the genuinely international psychology that is only just emerging today, and to which the "cultural-historical" psychology of the Soviets was a precursor.

The legacy of Vygotsky and his colleagues (most importantly, A.R. Luria and A.N. Leont'ev) is also illuminating in another, more specific respect. It can shed light on the mechanisms of knowledge transfer from one cultural context to another—a process central to the transmission and globalization of knowledge. The Soviets created a new psychology out of old resources. They heavily relied on the work of Western psychologists, which they integrated and revised to meet the unique needs of the new Soviet society. Their ideas, in turn, were later translated to new cultural contexts by their students in the West. Vygotsky hypothesized that local cultural conditions determine cognition. I reformulate this hypothesis as a question for the history of science: What happens to ideas when they travel? Understanding how knowledge is adapted to new cultural situations is key for the study of globalization, in history or now. Therefore, I start by examining how the local cultural context—post-Revolutionary Soviet society—influenced Vygotsky's reading of Western psychologists.

I focus on Vygotsky's reading of Jean Piaget, one of the most stimulating peers Vygotsky discovered in the West. In Section 26.2, I examine how Vygotsky understood Piaget's concepts of egocentric speech and cognitive egocentrism. On this basis, I propose a taxonomy of possible ways for a scientist to use the ideas of others. I discuss in what respects the work of Vygotsky and Piaget was specific to the respective social conditions in which it was produced. I conclude that recontextualization of ideas is to be expected when psychological knowledge is applied to new cultural situations. Psychology is a human and social science that cannot (and should not) be impervious to social needs, practices, norms, and values.

In Section 26.3, I discuss Vygotsky's "cultural-historical" program as an early experiment in creating an international psychology. This project arose in the cosmopolitan social and intellectual climate of the Soviet Union in the 1920s. I examine three aspects of the "cultural-historical" psychology that made it an international science—its cross-cultural orientation, its focus on the cosmopolitan individual, and its design as a comprehensive paradigm—and discuss why this program failed. In Section 26.4, I put cultural-historical psychology in the context of subsequent developments in psychology and the discipline's progress toward globalization. First, I survey how the ideas of Vygotsky and his colleagues were recontextualized by later generations of Western psychologists. Second, I take a broader look at the history of psychology as a story of gradual internationalization—an outcome that Vygotsky would welcome. Finally, I discuss how psychologists understand the globalization of psychology today, what goals they envision for the future, what obstacles impede globalization, and what today's emerging global psychology owes to the work of Vygotsky and his colleagues.

26.2 What Happens to Ideas When They Travel

The Revolution made it exciting to be a psychologist in the Soviet Union. The new regime posed unprecedented pragmatic challenges, such as teaching literacy and professional skills to massive numbers of peasants across the vast expanses of the new federation, the socialist education of children (including seven million homeless orphans and many children with special needs[1]), increasing efficiency at the workplace, and, more generally, explaining the human psyche in the context of socialism. The radical Soviet intelligentsia sensed a clean break with the past. Experimentation and pluralism flourished until the late 1920s and early 1930s; after that time the arts and the sciences became increasingly subject to central control, politicization and repression.[2] Vygotsky, Luria and Leont'ev saw themselves as the vanguard of psychology, who had an opportunity to revise the very foundations of the psychological science and to create something new.

Despite their eagerness for innovation, the Soviet psychologists paid close attention to the work of their Western colleagues. They were fluent in foreign languages and had access to Western literature. They maintained contacts with

[1] See (Ball 1993, 229).
[2] See, for example, (Yaroshevsky 1992, 1994; Petrovsky 2007).

foreign colleagues through travel (whenever political circumstances allowed) and correspondence. In fact, Vygotsky's writings were so densely filled with references to Western psychologists (such as Adler, Bühler, Claparède, Freud, James, Janet, Köhler, Koffka, Lewin, Piaget, Stern and Werner) that he was accused of bourgeois leanings.[3] Despite the Iron Curtain (which descended almost immediately after the Revolution in 1917), throughout his life Luria succeeded in regularly publishing in the West and enthusiastically took on and supervised foreign students.[4]

The Soviet psychologists were highly critical in their approach to Western sources. They read Western psychology as a story of limitations, side by side with successes.[5] They tested and falsified certain claims[6] and tried to incorporate the achievements of Western psychologists in their own theory and methodology. They intended their research program to be global in scope—both in the sense that they envisioned it as international, and in the sense that they sought a unifying paradigm to replace the various distinct schools of psychology that were current at the time.

Psychological ideas were transformed as they traveled from the West to the USSR. As a case study of such a transformation, I will focus on Vygotsky's interpretation and use of Piaget's concepts of egocentric speech and cognitive egocentrism.[7] Vygotsky's reading of Piaget was a "creative misreading." Vygotsky approached Piaget critically, with a radically different set of philosophical commitments, and in the context of a radically different socio-economic reality. Vygotsky worked in the USSR and was a materialist and a Marxist, committed to the centrality of labor in cognitive development. By contrast, Piaget studied Swiss children, in what Vygotsky conceived of as a bourgeois setting; moreover, Vygotsky identified idealist commitments in Piaget's thinking.[8]

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[3](Rudneva 1937), cited in (Petrovsky 2007, 45).

[4]See (Luria 1994; Kuzovleva 1999; Cole et al. 2006).

[5]See (Leont'ev 2000; Vygotsky 2006a; Cole et al. 2006). According to Vygotsky, one such fundamental limitation consisted in the inability of Western psychologists to conceptualize the connection between the individual and the social; thus he claims that "they have not known social psychology in the West" (Vygotsky 2006a).

[6]For example, Luria (1976) demonstrated that the "universal" laws of perception described by Gestalt psychologists (e.g., concerning the perception of geometrical figures) did not apply to Uzbek peasants who led a traditional lifestyle. Given that in the 1920s and 1930s Gestalt theory aspired to become the leading paradigm in psychology, Luria's findings proved that a global paradigm could not succeed unless it was able to explain cultural variation in behavior and cognition.

[7]Based on Piaget's four early studies (1928; 1929; 1930; 1959), the only ones available to Vygotsky in his lifetime.

[8]Vygotsky considered Piaget an idealist on the following grounds: Piaget refused to commit to ontological realism and take a strong (i.e. materialist) conception of causality; he declared "sociological" and "biological" modes of description as alternatives; and he considered the logic of the scientist as an alternative to the logic of a child (Vygotsky 2005a, 58–61, 64–68). Vygotsky claimed that as a consequence of his weak concept of causality, Piaget failed to explain how development happens. For Piaget, the egocentric thinking of a child is *replaced* by logical thinking; the child "weaves on two looms," in Claparède's expression (Vygotsky 2005a). Yet Piaget did not

Piaget (1959) defined *egocentric speech* as the child's speech addressed to itself (in either the presence or absence of others) and *cognitive egocentrism* as the child's inability to imagine things from another's perspective, which fundamentally constrains the child's reasoning. Piaget observed that children developed cooperation and "sustained social intercourse," based on mutual understanding, no sooner than age seven or eight. Before this age, they were intellectually "egocentric," owing to weak "differentiation between another and the ego," and produced copious egocentric speech (Vygotsky 2005a, 243). Piaget assumed that egocentric speech was an outward manifestation of cognitive egocentrism. He theorized that the child developed from individualism toward an increasingly social orientation (Piaget 1959, 40).

Below I will specify four ways in which Vygotsky responded to Piaget's ideas. They constitute four basic options that a scientist has when borrowing from the work of others, or four basic moves in the transmission of knowledge.

26.2.1 Acceptance and Incorporation

Vygotsky accepted some ideas of Piaget and incorporated them into his own theory. For example, Vygotsky accepted Piaget's conclusion that the child's reasoning is genetically rooted in interpersonal argument (an idea that, according to Vygotsky, originated from Baldwin).[9] Vygotsky used this idea as an example of interiorization—a transfer of social functions into the psyche—that drives development. (Vygotsky borrowed the concept of interiorization from Janet and extended it (Vygotsky 2006b, 351–353).)

26.2.2 Grounded Rejection

Vygotsky's cultural situation led him to reject some of Piaget's ideas about egocentrism.

1. He claimed that Piaget's interpretation of the child's peculiar way of thinking as a biological universal rested on limited and insufficient data (Vygotsky 2006d, 702, 735). Piaget relied on his particular observations of Swiss children at the Maison des Petits in Geneva. These children's relatively late socialization, Vygotsky argued, might be attributed to sociocultural factors. Soviet children, by contrast, exhibited a different pattern of socialization. At home and in the nursery they were encouraged to engage in close collaboration from an exceedingly young age.[10] Piaget, in Vygotsky's view, imagined

explain how the integration occurs, i.e. how logical thinking arises on the basis of the egocentric substrate.

[9] "Reason-giving initially arises in an argument between children and only then is transferred inside the child; [...] thinking is born in argument" (Vygotsky 2006b, 351, 357).

[10] In *Thought and Language* Vygotsky did not describe in detail the empirical, experimental observations that drove his criticism of Piaget's work. We owe an account of Vygotsky's reasoning from empirical data to Levina (2001), a young member of his experimental team. Vygotsky also tacitly relied on his experience of interacting with Soviet children as part of his extensive

children as living in what we might call a "Charlie Brown world," where adults play essentially no role in the child's social development, and interaction with peers is all-important.[11] Vygotsky rather conceived of children as immersed in the world of adults and developing in response to adults and more mature peers (thus the child developed in what Vygotsky called the "zone of proximal development"[12]).

2. Piaget interpreted children's thinking as "autistic" (a concept he derived from Bleuler)—a kind of dream-like fantasy, governed by desires, unaware of itself, strictly private and not communicable. Vygotsky found this view of the child's thought flawed, since it did not do justice to the child's participation in labor. For Piaget the child's play was a purely imaginative symbolic activity opposed to everyday reality. But Vygotsky observed that the child's play, however imaginative, *imitated* reality and prepared the child for an active role in society (Vygotsky 2006e). Piaget compared the child's thinking to that of the "primitive," where both were largely impervious to reality: "Experience undeceives […] [the savage] only on very special technical points (cultivation, hunting or manufacture) […]" (Piaget 1928, 203). Yet, as Vygotsky objected, for primitive people "cultivation, hunting, or manufacture" constitute not "narrow technical cases" but the very substance of their life (Vygotsky 2005a, 7). Similarly, in the Soviet Union the child's play imitated practical activity, the labor that determined social reality (Vygotsky 2005a, 72).
3. Piaget believed that logic originated in interpersonal communication—in argument, as minds adapt to each other. From Vygotsky's perspective, Piaget's hypothesis ignored the importance of the practical activity that gives rise to argument and imbues it with content (Vygotsky 2005a, 65, 68–69).
4. Piaget considered syncretism a vestige of the child's egocentrism. For Vygotsky, it was a tool for organizing and comprehending the world—a source of hypotheses concerning unfamiliar objects against which the child is able to evaluate new experiences.[13]

26.2.3 Adaptation

Vygotsky did not merely criticize Piaget; he also adapted Piagetian ideas, which took on a different significance in Vygotsky's cultural matrix.

1. Piaget considered egocentric speech as evidence of the child's inability to engage with the social, or real, world—a mere "accompaniment" to the child's

pedagogical and clinical work, as well as on the observations of his own children (Vygotskaya and Lifanova 1996; Yaroshevsky 2007).

[11] (Piaget 1959, 5); cf. (Bruner 1985, 25).

[12] Vygotsky (1978, 86) defined this zone as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or collaboration with more capable peers." See also (Levina 2001, 81).

[13] Cf. (Markman 1989; Vygotsky 2005a, 71).

actions. By contrast, Vygotsky saw it as a developmental milestone. Vygotsky demonstrated that egocentric speech performed an important intellectual function, overlooked by Piaget—the function of planning behavior—and that it was a transitional stage in the development of inner speech. Thus egocentric speech took on a new function and character in Vygotsky's work; the concept was transformed.

Vygotsky conducted a series of experiments, prompted by Piaget's work on egocentric speech, and on their basis he developed the following account of the genetic relationship of language and thought (Vygotsky 2006e). First speech serves as a means of communication with elders. Then it develops a demonstrative function, when a child learns to identify objects in reality "for oneself" (first the child notices how language ostensively marks objects "for others"). Speech becomes a tool for the internal representation of external reality. It breaks the child's sensory-motor syncretism and captures the essential; it creates schemata of experiences (Levina 2001, 84).

At this stage "speech becomes an investigator, a means [...] of mastering the world" (Levina 2001, 82). While Piaget interpreted this kind of speech as superfluous, Vygotsky claimed that it performed a "gnostic" ("reflective" or "reporting") function. Subsequently the child starts using egocentric speech to plan behavior when it experiences obstacles. Planning speech is also schematic, but it is oriented toward action. Planning speech liberates the child from the "optical intellect" (i.e. the intellect limited by the visual field, as characteristic of apes[14] and small children[15]) and makes symbolic thinking possible (Vygotsky 2006e).[16] Planning speech arises in the presence of others and thus in an inherently social context (Levina 2001). By naming things, the child makes them both shareable and intelligible. Planning speech becomes the primary tool of self-regulation.[17]

2. Criticizing Piaget allowed Vygotsky to emphasize an important perspective on development. According to Vygotsky, Piaget wrongly considered "autistic thinking" as a starting point of development, which progressed toward increasing socialization of the individual. Vygotsky proposed a different order: the child develops from a less differentiated consciousness of social relations toward individuation, as it learns to use speech for self-regulation (Vygotsky 2006b, 357). Piaget worked in a capitalist society in which the individuation of the person was taken for granted, and the individual needed to be socialized. By contrast, Vygotsky worked in a communist society that took

[14] Cf. (Köhler 1915).

[15] Cf. (Bühler 1930).

[16] Experiments demonstrate that children who are asked to vocally plan their actions reach beyond the situation in two ways: (a) they physically look around, and (b) they think about a possible course of action by reverting to past experience (Levina 2001, 88). Thus language creates psychological time: it sets the present against the past, and it stores present impressions for the future (Tomasello 1999; Levina 2001, 88).

[17] Cf. (Janet 1929; Vygotsky 2006b, 351).

the collectivist situation of the person for granted. In Vygotsky's thinking, thus, it was individuation that the person had to develop.

26.2.4 Omission

Certain of Piaget's ideas simply did not travel. They were incomprehensible where they did not fit.

1. Vygotsky misunderstood the importance of Piaget's concept of cognitive egocentrism, "the inability to differentiate between one's own point of view and those of others."[18] Piaget stressed that children learn to cooperate—and to communicate effectively through language—only gradually, and often fail. Failure to adapt to another's perspective does not fully disappear in adulthood (Piaget 1929).[19] A theory of development must account for these failures. Vygotsky disregarded this challenge, along with the plentiful evidence for cognitive egocentrism in the four studies by Piaget.[20]
2. Vygotsky misunderstood the meaning of "the social" in Piaget. By "the social" Piaget meant "intellectual cooperation" between individuals, which depended on the ability to communicate one's thoughts and to understand the thoughts of others.[21] Vygotsky found this dimension of social life "uninteresting" (Piaget 2000, 248). Vygotsky understood "the social" as the cultural and stressed the role of symbols, tools and activities in cognitive development.[22]
3. Vygotsky emphasized the role of language in cognitive development. He explained the genesis of *verbal* thinking and recognized that language performs different functions in cognition and social life. Yet he underestimated the importance of Piaget's perspective on "intellectual operations," or *non-verbal* thought (as in logic and mathematics). He did not acknowledge *reasoning* as a problem in its own right: How does the child learn to reason about "what there is" from different perspectives, with and against others? Vygotsky explained cognitive maturation in terms of conceptual change, as the

[18]See, for example, (Piaget 1929, 167–168).

[19]Piaget rightly accused Vygotsky of "excessive bio-social optimism" (Piaget 2000, 243). There is political irony in Vygotsky's ignoring the importance of cognitive egocentrism. The failure of socialism in Eastern Europe can be attributed to the fact that communist theorists took social cooperation too much for granted, overestimating the natural human desire for brotherhood. Vygotsky himself greatly suffered from intellectual misunderstanding in the Soviet psychological community, especially in the 1930s (Vygotskaya and Lifanova 1996).

[20]Piaget's early results have been repeatedly replicated, extended, and many of his conclusions confirmed. For example, in the 1980s Soviet psychologists conducted Piagetian studies of Moscow children in order to test whether their logic and conception of the world differed from those of Piaget's subjects in the 1920s (Obukhova 1981). Soviet researchers concluded that, despite some differences in the content of thought, Muscovite children exhibited the same general cognitive tendencies (realism, animism, artificialism, syncretism and so forth) and often gave the same answers as Piaget's children (Obukhova 1981, 98–99).

[21]See the final chapter of (Piaget 1959); cf. (Piaget 2000, 249).

[22]See, for example, (Vygotsky 2006e).

child learns to understand the world increasingly by means of "scientific," as opposed to "spontaneous," concepts (for Vygotsky this change largely occurs through education (Vygotsky 2005a)). Yet concepts have to be studied side by side with reasoning structures that relate concepts to each other.[23]

Vygotsky offers a rich account of concepts and an impoverished account of reasoning. Piaget presents a rich account of reasoning and an impoverished account of concepts.

Why does Vygotsky miss these important ideas of Piaget? Vygotsky underemphasized everything that had to do with interpersonal understanding, reasoning and dissent—issues that Piaget regarded as central. He failed to recognize social cooperation as a problem because he was immersed in a collectivist culture that took cooperation for granted. For Vygotsky the central problem was the acquisition of culture—a problem that arose from the exigency of spreading cultural tools (such as literacy) in the early Soviet Union, which entailed integrating vast populations into a new system of production.

In his response in 1962 to Vygotsky's criticisms, Piaget identified some points of disagreement, but failed to acknowledge the complementary strengths of Vygotsky's approach and Vygotsky's reasons for pursuing it (Piaget 2000). Thus, the two psychologists had blind spots when reading each other. However, their creative misunderstandings can hardly be considered a defect, or a failure of scientific thinking. Their reading each other proved to be highly productive, for it allowed them to refine their concepts and methods and, in the case of Vygotsky, to develop new ones. Neither Vygotsky nor Piaget was fully persuaded by each other's choices, but each continued to build knowledge within his own framework.

In his treatise on the methodology of science, *The Historical Significance of the Crisis in Psychology*, Vygotsky claimed that no scientific concept could be transplanted into another research program without modification (Vygotsky 2006a). The reason for this is that every scientific concept is in its deep logical structure inextricably connected to the methodological and philosophical principles on which the program is based. For a successful transfer, either the programs have to be methodologically compatible, or the concept has to be used heuristically—that is, as a rather loose prompt for original research, rather than a ready-made building block to be imported uncritically into a research program (Vygotsky 2006a, 92). Besides these methodological constraints, the process of knowledge transfer is influenced by social and cultural factors. As members of their societies, psychol-

[23]Modern psychologists have tried to find ways to reconcile the Piagetian and Vygotskian approaches (Wozniak 1996). One possibility of the synthesis is suggested by Wittgenstein. Like Vygotsky, Wittgenstein maintained that language performs multiple functions, or uses. Like Piaget, he questioned how language can be used for thought in a social scenario. Wittgenstein's concept of "language games" explains this process: People construct language within a shared activity, i.e. the meaning of linguistic units emerges in the context of mutually understood practical actions. This view combines Piaget's focus on intellectual operations as they originate in social actions with Vygotsky's (Marxist) focus on language as inscribed in practical activity, cf. (Malinowski 1923; Piaget 1951, 2001, 138–140;) on gesture and action in play.

ogists consciously or unconsciously bear social agendas that reflect the needs and emphases prevalent in these societies. The more they are at home in their time and place, the more we should expect that they will be creative when appropriating the ideas of others.

26.3 Soviet Psychology as International Psychology

The Soviet Union in the 1920s was international in outlook: The ideological and intellectual climate in the aftermath of the Revolution was cosmopolitan. For Vygotsky and his students, internationalism was also reflected in their broad prerevolutionary education and cultural interests. The psychology they attempted to create was international in three respects.

26.3.1 Soviet Cross-Cultural Psychology

First, Vygotsky and his students believed that psychology had to account for cross-cultural variation in human cognition and behavior.[24] They proposed a research program that could reveal the role of culture in development. This program, known today as "cultural-historical" psychology, aimed at an understanding of the role of both biological and sociocultural factors in development; an explanation of cultural differences in cognition and psychic life; and an account of the most complex forms of cultural behavior and consciousness, such as reading, writing and thinking. To achieve these goals, Vygotsky and his students initiated a series of empirical studies, including experimental studies of memory, concept formation and problem solving,[25] as well as cross-cultural studies of cognitive processes of the peasant population in Uzbekistan (Luria 1979).

Vygotsky, Luria and Leont'ev worked at a time when Soviet scholars showed great interest in comparative studies of the populations of the USSR. In the 1920s such studies were conducted extensively by pedologists and psychotechnicians—researchers who performed anthropometric and psychometric studies of children, and assessed individuals' fitness for professions, respectively. Pedologists and psychotechnicians conducted extensive studies of different groups of the Soviet population, across class and ethnic boundaries, including for the first time the "national minorities"—such as the peoples of Central Asia, Siberia, the Caucasus; Tatars; Bashkirs; and Jews. These disciplines employed standardized, international metrics (such as Pignet index measurements; the tests of Binet-Burt, Binet-Termin, Binet-Simon, Rossolimo, Levitov-Tolchinsky; questionnaires investigating children's interests and ideals, and tests on moral conflicts (Kurek 2004, 25–26)). The generalizations made on the basis of these data turned out to be politically disturbing. Slavic peasants and workers showed considerably lower IQ

[24]They were not alone. In the early twentieth century, many European researchers were developing accounts of cross-cultural variation, often in the context of discussing the relationship between ontogeny and phylogeny, see (van der Veer and Valsiner 1991, 190).
[25]See (Leont'ev 1983; Shif 1935; Vygotsky and Sakharov 1998; Levina 2001).

and other measures of psychological development than the Slavic urban educated classes. The Turkic populations of Central Asia scored even lower.[26] The resulting data were in stark conflict with the official Soviet ideology of social progress and the radical plasticity of humans. Consequently, in 1936 pedology and psychotechnics were banned by the Soviet authorities, testing and cross-cultural psychometric studies were prohibited, and the leaders of pedology and psychotechnics repressed.

The work of the pedologists and psychotechnicians was an important foil for Vygotsky and his students. Vygotsky claimed that standardized testing, no matter how much adjusted and improved, could not serve as an adequate approach to the study of ethnic minorities. What was needed instead, he argued, was to explore the problem of cultural development through broad empirical studies and an ambitious theoretical program (Vygotsky 2004). Vygotsky stressed that cognition could not be studied in isolation from the structure of the environment, i.e. from everyday cultural forms of behavior, the history of the social group, its economy, art forms and so forth (Vygotsky 2006e, 226, 234). Cross-cultural studies had to proceed hand in hand with research on psychological functions (see below), which would reveal laws of cultural development. Vygotsky argued for the creation of a special research institute for the pedology[27] of national minorities, which would direct and coordinate cross-cultural investigations across the Soviet Union (Vygotsky 2004).

Vygotsky and Luria claimed that Rossolimo and Binet's intelligence tests measured at best the knowledge the child had already acquired at school, but that they failed to measure the child's intelligence as a capacity (Vygotsky and Luria 1930, 220, 226–231). For cultural-historical psychologists, intelligence consisted in the ability to use cultural, rather than natural, resources to solve problems. This ability, they proposed, could compensate for the lack of natural endowment (as sign languages function for the deaf and mute). During his expedition to Uzbekistan in 1931–1932, Luria assessed not only the performance of the local population on cognitive tasks, but also their zone of proximal development. This method, developed by Vygotsky, allows psychologists to assess an individual's potential for learning; it measures how well a subject performs a task when offered assistance. Luria (1979) showed that the Uzbek subjects possessed a high zone of proximal development. With minimal education they quickly acquired the more abstract, categorical forms of cognition typical of an educated urban population.

26.3.2 Vygotsky's Focus on the Psychology of the Cosmopolitan Individual

Second, Soviet psychologists were interested in creating a psychology and a pedagogy that would facilitate the production of "the new man"—the ideal Soviet

[26] According to A. Stilerman (1928), cited in (Kurek 2004, 41), only 16.8% of Uzbek children qualified as normal in intellectual development, 63.3% as slightly retarded and 19.8% as severely retarded; they were 2–5 times less developed intellectually than Russian children.

[27] By this term Vygotsky meant an integrated study of the child, including fields that were in practice separated, such as developmental psychology, pedagogy and pediatrics.

citizen, whose outlook was cosmopolitan rather than national. This orientation is especially pronounced in Vygotsky's *Pedagogical Psychology* (1926). Vygotsky stressed that contemporary developments in economics, science and technology were happening on a world scale and could only be understood on a world scale (Vygotsky 2005b, 248). Therefore, to excel in any of these domains one had to comprehend global tendencies (this argument is *a fortiori* relevant today) (Vygotsky 2005b, 259). Vygotsky, Luria and Leont'ev were living examples of this ethic. They attempted to create a new international psychology in dialogue with Western psychologists and thinkers.

26.3.3 The Soviets' Attempt to Create a Comprehensive General Psychology to Replace the Multiplicity of Schools and Paradigms

Third, Soviet psychologists attempted to create a single scientific psychology. According to Vygotsky, psychology in the 1920s was torn between two irreconcilable tendencies: (1) Materialist, causal, or explanatory psychology, which employed inductive and "objective analytical" methods (e.g., reflexology and behaviorism), and (2) idealist, descriptive, or teleological psychology, which employed introspection (e.g., Husserl's phenomenology and Wundt's introspectionism) (Vygotsky 2006a). Vygotsky envisioned a unified discipline—not as an amalgam of all schools, but as a qualitatively new paradigm that would stress the centrality of development in a culture (the emphasis that was missing in European and North American psychology). This paradigm would remain materialist, but it would not be reductivist. It would not ignore the real complexity of human consciousness and behavior. Cultural-historical psychology was the Soviets' attempt to create this paradigm.

As the core of cultural-historical theory, Vygotsky proposed to explain the genesis of the higher psychological functions, which he saw developing along similar lines in phylogeny and ontogeny. For Vygotsky, *higher psychological functions* are complex capabilities—such as voluntary attention, categorical perception, purposive memory, will, concept formation, and reasoning—that develop from a biological substrate through processes of acculturation, or socialization. The genesis of the higher psychological functions depends on the mastery of "external means of cultural development and thinking," such as tools and various semiotic systems (language, writing, counting, drawing, art and so forth, (Vygotsky 2006b, 227, 2006e)). The *cultural development of behavior* involves the interplay of external and internal processes. As the child internalizes cultural signs (originally means of social interaction), it learns to *regulate its own behavior*. It comes to recognize a sign "for others" as a sign "for oneself" and to use it in order to organize its own thoughts and actions.[28] Vygotsky considers self-regulation as the highest human capacity.[29] A human is *homo faber*, who "*builds* new organs," i.e. higher

[28]Here Vygotsky follows Janet; see (Vygotsky 2006b, 329–322, 351–357, 2006c).
[29]Cf. (Lewin 1935), see (Vygotsky 2006b, 328–329, 2006f, 1124–1125).

psychological functions, through instrumental activity in the process of social life (Vygotsky 2006c, 1020–1021, 1028, 2006f).

26.3.4 Why Cultural-Historical Psychology Did Not Succeed

Cultural-historical psychology, as a comprehensive research program that would uncover the laws of ontogenetic and phylogenetic development, failed.

Some reasons for this failure were external. Vygotsky died in 1934, having scarcely tapped his intellectual and organizational talents. Whereas Soviet culture in the 1920s was characterized by boundless optimism and unbridled creativity and experimentation, the end of the decade brought increasing repression and state interference in scientific research. The early cosmopolitan outlook of the USSR yielded to inward-looking paranoia. Vygotsky and Luria's cross-cultural studies were attacked on ideological grounds,[30] Luria's work in Uzbekistan was discontinued, with his results remaining unpublished until the 1970s. This empirical project, however, was crucial for the cultural-historical program, and the inability of the Soviet psychologists to continue cross-cultural work severely crippled their research.[31] After 1936 Vygotsky's work was banned for decades. Luria and Leont'ev faced tremendous ideological and administrative obstacles in their later work. Moreover, at no stage did Vygotsky and his students have an adequate infrastructure for the research they envisioned. Although Vygotsky's students communicated with one another, they never worked together at a single institution (and in fact, political exigencies forced Luria repeatedly to move from institution to institution, abandoning earlier lines of research and taking up new ones).

Some reasons for this failure were internal. If external circumstances had been more favorable, was cultural-historical psychology a viable research program that could have had international uptake? What limited Vygotsky's efforts was the overemphasis on theory at the expense of systematic empirical work. Cultural-historical theory was indeed supported by some experiments (e.g., on egocentric speech, memory and concept formation) and clinical observation (e.g., Vygotsky's extensive work with abnormal children).[32] But a careful record of these procedures, such as protocols, is conspicuously missing in Vygotsky's published work. He tends to describe his data only briefly and focuses on conclusions from and ramifications of the data, rather than on the process of inference. Vygotsky considered his role as a reformer of psychology, who could create new theory and institutions. Diagnosed with terminal tuberculosis, he rushed to develop ideas, which his students could further elaborate and test through experimental research. Vygotsky acknowledged that his cultural-historical theory was only an

[30] See (Vygotskaya and Lifanova 1996; Razmyslov 2000; Kurek 2004, 121).

[31] See (Vygotsky 1996).

[32] Most of these experimental data have never been published, and, given the complexity of the archival situation and possible attrition of materials, it is not even clear which remain extant. Some have been published in the work of Vygotsky's students, see, for example, (Shif 1935; Leont'ev 1983; Levina 2001).

"abstract development of concrete psychology" of social groups—a prolegomenon to detailed studies of cross-cultural difference and cultural development (Vygotsky 2006c, 1030). His texts are rich in ideas, but he failed to develop many of these ideas into genuine scientific concepts. Vygotsky's specific research methods were interesting and innovative;[33] his understanding of methodological problems of psychological science was quite refined;[34] and his depth of analysis of specific experiments and observations was remarkable;[35] but he failed to create a comprehensive methodology that would translate cultural-historical theory into an actionable research program.[36]

Similarly, Leont'ev devoted himself largely to theory building. In his later years, he confessed that he regretted not having created a fuller empirical basis for his theory (Leont'ev et al. 2005). Luria was the only member of the troika who made himself into a systematic empirical investigator. He called the early methods of cultural-historical psychologists "banal in and of themselves": "Today we would consider them no more than student projects," or "pilot studies." He acknowledged, however, that "the general conception that organized these pilot studies [...] provided a set of experimental techniques which [he] was to use throughout the remainder of [his] career" (Cole et al. 2006, 51). The experiments of cultural-historical psychologists, no matter how promising, did not amount to a systematic experimental program that would lend proper empirical grounding to a new psychology.

The Soviet psychologists, in giving short shrift to experimental documentation and empirical research, separated themselves from their Western colleagues who were actively collecting and publishing their data. Vygotsky criticized Wundt and Freud for their theoretical assumptions, but he seemed to miss the rigor of the Wundtian laboratory, as well as the thoroughness of Freud's clinical descriptions. We must remember that scientific knowledge depends not only on insightful ideas and the depth of analysis, but also on the sheer bulk of empirical work that can prove and refine ideas. When Western psychologists came to read the texts by the Soviets, they read them in the context of an empirically based program of research, naturally assuming that the ideas of Vygotsky and others could be tested in the laboratory. The Soviet cultural-historical school was important and innovative; many of its ideas have been taken up by Western psychologists, and it still contains lessons concerning the depth and breadth of scientific thinking. Sadly, Russian psychology still remains largely isolated from the international

[33] For example, in the studies of egocentric speech, prompted by Piaget, Vygotsky combined experiment, clinical observation and pedagogical intervention (the technique is described in (Levina 2001)).

[34] See, for example, (Vygotsky 2006a).

[35] For example, he drew his understanding of the genetic relationship between thought and language from his investigations of egocentric speech, see (Vygotsky 2005a, 282–347), including his observation of his own children, see (Vygotskaya and Lifanova 1996); an example is described in (Vygotsky 2005a, 44).

[36] See (Lamb and Wozniak 1990; Cole 1995).

mainstream, and current researchers tend to develop elaborate theoretical edifices that rest on limited real data.

26.4 Recontextualization of Soviet Psychology and the Growth of a New International Psychology

26.4.1 Recontextualization of Soviet Psychology

Certain ideas of Soviet psychologists were taken up, primarily in America, starting in the 1960s, especially in two areas: in psychology of language and in pedagogy. Interest in Vygotsky's school resulted from a kind of internationalization—a thaw in the relations between the US and the USSR. Vygotsky's work was discovered in the West through two publications: the translation of *Thought and Language* by Hanfmann and Vakar (1962) and the compilation of Vygotsky's cultural-historical writings *Mind in Society: The Development of Higher Psychological Processes* (1978). After 1956, the Soviet authorities allowed Luria to travel; he attended many international conferences and hosted many foreign students (Luria 1994; Kuzovleva 1999). Since the 1960s, his books have been widely published in the West. One of Luria's works (1932) was even published in English before it appeared in Russian (2002). Leont'ev's work was discovered in the West somewhat later. His important *Problems of the Development of the Mind* (1959) appeared in English only in 1981. His other major works remain largely untranslated and in fact only now are some being published in the original Russian (Leont'ev 2000). Leont'ev's version of activity theory initially attracted the attention of Finnish and Scandinavian researchers (Engeström 1987), and recently it has become influential in North America as well (Wertsch 1981).

The enthusiastic reception of Soviet psychologists in the West cannot be attributed merely to the publication of their work in translation (translations, which in fact often left much to be desired, in some cases were only partial, and lacked—and still lack—a proper scholarly apparatus). Rather, Western researchers and educators took up the work of the Soviets because it seemed to fill certain gaps and answer important questions that had hitherto remained unanswered.

In developmental psychology, Vygostky's approach offered a promise of a theory that would integrate and explain a wealth of empirical data that lacked an overarching theoretical framework.[37] The reception of Vygotsky was also facilitated by social factors—such as American educators' growing interest in a pedagogical reform that would de-emphasize the traditional, individualist view of learning. Pedagogy and child psychology were moving away from a reliance on behaviorist models. They needed a new paradigm, and in the context of increasing liberalism (partly provoked by the Vietnam war) the Vygotskian approach seemed particularly appealing. The new, Vygotskian perspective stressed that the child is embedded in a social context. From this perspective, children learn together

[37] (Goswami 2002); cf. (Rowe and Wertsch 2002).

and from one another; one teaches not individual children but the whole class; adults as well as more advanced peers play a key role in the child's cognitive development. In fact, Vygotsky's concept of the zone of proximal development has been emphasized by those who react against political pressures for standardized academic testing in the US (Rowe and Wertsch 2002, 552).

Vygotsky greatly influenced (largely through *Thought and Language* and the experimental elaboration of some of his ideas by Luria[38]) Western psycholinguistics,[39] literacy research[40] and research on concept formation.[41] He has been read and recontextualized by cognitive psychologists (Bruner 1985; Frawley 1997) and evolutionary psychologists (Tomasello 1999). His work (along with that of Leont'ev) has inspired research on distributed cognition, which studies how knowledge is acquired and distributed in a group, such as an institution.[42] Perhaps most significantly, Vygotsky's work became the foundation stone for cultural psychologists, who have taken his insights to a new level.[43]

Luria has exerted an extensive influence on neurologists and aphasiologists all over the world.[44] He played a fundamental role in the rise of neuropsychology, now a flourishing field. Luria was found to be the most frequently cited Soviet (Russian) psychologist in North America (Solso and Hoffman 1991). Despite rapid advances in neuropsychology, he continues to play a key role in the field. According to a 1996 survey (Ryan and Bohac 1996), Luria's *The Working Brain: An Introduction to Neuropsychology* (1973) and *Higher Cortical Functions in Man* (1980) remain among the top essential readings in neuropsychology, and, if duly updated, have every reason to stay relevant (Tupper 1999, 2–3). Luria's influence on Western neuropsychology—a field dominated by narrow empirical results—can be attributed to his emphasis on an overarching framework (rooted in Vygotsky's cultural-historical theory) that can help explain and integrate many empirical findings (Tupper 1999, 1). Luria also brought to neuropsychology a distinctive perspective that differs markedly from North American approaches. Whereas North American neuropsychology tends to rely on quantitative methods applied in group studies (an approach derived from psychometry), Lurian neuropsychology stresses the clinical assessment of individuals in single case studies, with a focus on identifying links in the functional system of cognitive processes in

[38] See, for example, (Luria 1959, 1961).

[39] For example, (McNeill 1970, 1992; Bowerman and Levinson 2001).

[40] For example, (Scribner and Cole 1981; Tobach et al. 1997; Lee and Smagorinsky 2000; van Kleeck 2004; Singer and Bashir 2004).

[41] For example, (Keil 1989; Mandler 2004). Vygotsky's work on conceptual thinking in schizophrenia influenced Western researchers from the 1930s on, see (van der Veer and Valsiner 1991, 278–283); cf. (Mandler 2004).

[42] See (Douglas 1986; Resnick et al. 1991; Cole and Engeström 1993; Salomon 1993; Rogoff 1994, 1998; Zhang and Norman 1994; Hutchins 1995; Leigh et al. 1999; Perry 2003; Gureckis and Goldstone 2006; Ross et al. 2007).

[43] See (LCHC 1982; Cole 1995, 1996, 1999, 2006; Cole et al. 1997; Tobach et al. 1997; Valsiner 2000).

[44] See (Goodglass 1993; Das 1999; Tupper 1999).

the context of the patient's personality (an approach derived from clinical neurology and psychology).[45]

In developing his theory and methods, Luria demonstrated his commitment to combining "classical" and "romantic science"—a distinction first introduced by Max Verworn. Classical science is reductivist, analytical and logical; it aims at constructing abstract models of phenomena and discovering universally applicable laws. In contrast, romantic science resists "splitting living reality in its elementary components" and aims to capture the real, systemic complexity of "life's concrete events" (Cole et al. 2006, 174–175). Without denying the advantages of "classical" reductivism, Luria insisted on the importance of clinical observation, description and analysis of individual case studies, in the tradition of nineteeth-century medicine (Cole et al. 2006, 176–177). He pioneered a new genre of scientific writing, in which he presented literary portraits of his patients in the context of "classical" scientific analysis of their pathologies: *The Mind of a Mnemonist* (1968) and *The Man with a Shattered World* (1972). The genre of "romantic essay" was enthusiastically picked up most notably by Oliver Sacks,[46] but also by many others.[47]

Leont'ev's activity theory—a framework for understanding how subjects achieve their goals (e.g., in the workplace) through the mediation of tools and artifacts—was taken up by researchers interested in the study of contemporary work practices, such as practices of production (e.g., in industry and in research institutions), as well as in organizational learning and communication, knowledge transmission, innovation, network collaboration, product evolution, motivation and decision making in the workplace.[48] Leont'ev's theory was adapted to Western working conditions (e.g., the concepts of "community" and "rules" were introduced). It has recently acquired significance in the fields of human-computer interaction, information systems and software design.[49]

A number of Western psychologists played a key role in bringing Soviet psychology into the mainstream. Foremost is Michael Cole, who studied with Luria in Moscow in the 1960s. Cole facilitated the spread of the ideas of the Soviets by editing the translation journal *Soviet Psychology* and several important books,[50] including Vygotsky's *Mind in Society* (1978). He now edits *Mind, Culture, Activity: An International Journal* and previously edited the *Journal of Russian and East European Psychology*, which is intended to familiarize the international psychological community with the current and historical work of Russian and Eastern European psychologists. James V. Wertsch contributed greatly to the explication

[45] See (Luria and Majovski 1977; Luria 1999; Tupper 1999, 3).
[46] For example, (Sacks 1973, 1985, 1995).
[47] For example, (Schaller 1991; Damasio 1994; Cytowic 2003).
[48] For example, (Engeström 1987, 1992; Hyysalo 2003; Engeström 2004, 2005; Miettinen 2006; Miettinen et al. 2008).
[49] See (Kuutti 1991; Nardi 1996; Bardram 1998; Redmiles 2002; Turner and McEwan 2003).
[50] See (Cole and Maltzman 1969; Cole 1978a,b; Cole and Cole 1979; Cole and Wertsch 1996; Cole et al. 2006; Daniels et al. 2007).

of the legacy of Vygotsky's school and its relevance for developmental psychology and education.[51] Jerome Bruner wrote the introduction to the first English translation of Vygotsky's *Thought and Language* (Hanfmann and Vakar 1962). Yrjö Engeström (1987) popularized and extended Leont'ev's activity theory. Rene van der Veer and Jaan Valsiner (1991) composed a definitive intellectual biography of Vygotsky.

Certain Western psychologists not only facilitated the spread of the ideas of the Soviets, but also developed these ideas as part of their own research programs. For example, Cole took the Soviet cultural-historical activity theory as one of the sources of his cultural psychology (Cole 1995, 1996). Bruner drew attention to Vygotsky's concept of the zone of proximal development and, moreover, extended it with his own concept of "scaffolding" (structuring the participation of the adult to promote learning) (Bruner 1983, 1986). Michael Tomasello (1999) employed Vygotsky in his evolutionary account of human cognition. David McNeill (1992) used Vygotsky's ideas on thinking and speaking in his theory of the unity of gesture and verbal thought.

What is common to all of these researchers is that they do not slavishly rehearse the ideas of the Soviets, but make critical and selective use of them, recontextualizing these ideas when necessary. In other words, just as the Soviet psychologists entered into critical dialogue with the authors they read, modern psychologists engage critically with the Soviets.[52] Vygotsky believed that one can only truly understand the work of others (i.e. analyze the methodological principles of psychological writings) if one reads this work in the context of one's own ongoing research (Vygotsky 2006a). Vygotsky himself, as well as his students, should be read this way. Psychological science proceeds by empirical work, not by theorizing *in abstracto*. Parroting the Soviets[53] is not going to produce any new knowledge.[54]

26.4.2 International Psychology: Its Origins and Present Status

History

Since Wundt founded the first psychological laboratory in Leipzig in 1879, psychology spread quickly around the world even in the first generation of Wundt's students, who took it to the US (Hall, Catell, Ladd, Angell, Tichener), Switzerland (Durr), Denmark (Lehman), Italy (Kiesow), Russia (Chelpanov, Lange), Georgia

[51]See (Wertsch 1981, 1985a,b, 1991).

[52]It is useful to remember in this context that Vygotsky himself was a great polemical reader, who passionately mined psychological literature for data and insights relevant to his own work, cf. (Vygotskaya and Lifanova 1996).

[53]See, for example, (Robbins 2001).

[54]I do not intend to criticize genuine historical and scholarly research, for example, (van der Veer and Valsiner 1991; Vygotskaya and Lifanova 1996; Yasnitsky and Ferrari 2008; Yasnitsky 2008, 2009).

(Usnadze), Japan (Matsumoto) and China (Yuanpei) (Lück et al. 1984). Psychological laboratories modeled upon Wundt's were rapidly established in these countries, as well as in France, the United Kingdom and India (Jing 2000, 573–574). In the beginning of the twentieth century, most psychological research was done in the US, Germany, Great Britain and France (Fuchs and Milar 2003). Throughout the twentieth century, the spread of psychology around the world was marked by the establishment of national psychological organizations, on the model of the American Psychological Association, which had been founded in 1892 (Rosenzweig 1992). By the end of the 1950s, most industrialized countries had a national psychological association, whereas in Latin America, Africa and most third world countries, psychology mainly developed after World War II.[55]

In different countries psychology had different roots and was influenced by different local traditions (Pawlik and d'Ydewalle 1996). Whereas psychological research in the US and Germany derived from the Wundtian experimental tradition (and in the US was quickly succeeded by behaviorism, starting with Watson, 1913), British psychology at its inception was strongly influenced by psychometrics (Galton, Pearson, Spearman) and French psychology by clinical analysis (Ribot, Janet, Binet). In China psychology (especially educational psychology) was influenced by Confucianism (Ching 1984; Higgins and Zheng 2002). In India, although mainstream psychology relied on Western concepts and methodologies (Asthana 1988; Pandey 1988), it subsequently developed in the context of classical Indian thought and practices.[56]

Even in the early period psychologists felt the need for international congresses. The first was held in 1889 in Paris, and subsequent congresses were held every three to four years (with an interruption between 1937 and 1948).

In the second part of the twentieth century, the move toward globalization took on increasing momentum. Two new trends were the rise of international psychological organizations and of journals explicitly devoted to international aspects of psychology. Three types of international organizations were formed:

1. General: the International Union for Psychological Science (1951),[57] the International Council of Psychologists (1959).[58]
2. Regional: the Interamerican Society of Psychology (1951) and the European Federation of Professional Psychology Associations (1981).
3. Specialized: the International Neuropsychological Society (1967), the International Society for the Study of Behavioral Development (1969), the Jean Piaget Society (1970), the International Association for Cross-Cultural Psy-

[55] Cf. (Pawlik 1985; Sinha 1987; Rosenzweig 1992; Jing 2000, 575). For a discussion of factors that determine the development of psychology in a country, see (Jing 2000, 575–577).
[56] For example, (Sinha 1980; Pande and Naidu 1992; Mishra 2006); for an example of work in this tradition written outside of India, see (Varela et al. 1991).
[57] See (Rosenzweig et al. 2000).
[58] See (Halpern 2008).

chology (1972), the International Test Commission (1974), (Pickren and Fowler 2003).[59]

These organizations serve to provide fora for the exchange of knowledge, to improve conditions for research, to raise the prestige of psychology upon which funding ultimately depends, and to establish standards of training and practice. Important journals devoted to international psychology include:

1. General: *International Journal of Psychology* (1965), *International Journal of Applied Psychology* (1951), *The International Journal of Psychotherapy* (1996), *World Psychology* (1995–1997), *Transcultural Psychiatry* (1956)
2. Regional: *European Journal of Social Psychology* (1971), *European Psychologist* (1996), *European Review of Applied Psychology, Scandinavian Journal of Psychology* (1960), *Journal of Russian and East European Psychology* (1962)
3. Specialized: *International Journal of Psycholinguistics* (1993), *The International Journal of Clinical Psychology* (2001), *International Journal of Disability, Community and Rehabilitation* (2002), *International Journal of Eating Disorders, International Journal of Testing* (2001), *International Journal for the Psychology of Religion* (1991), *The International Journal of Aging and Human Development* (1984), *International Journal of Cross Cultural Management* (2001).

In addition, reviews and special issues on international perspectives are published in such journals as *Annual Review of Psychology* and *American Psychologist*.

English is the lingua franca in psychology, yet psychologists recognize that research in other languages is often neglected as a result.[60] To increase the accessibility of publications in other languages, *PsycINFO*, the most comprehensive database of psychological literature, not only systematically catalogues non-English publications, but also includes English abstracts of works in other languages.[61] There are also translation journals, such as the *Journal of Russian and East European Psychology* (1962) and *The German Journal of Psychology* (1977).

In the past few decades, the trend toward globalization in psychology has gained considerable momentum. Today psychological research not only welcomes international collaboration but depends on it. Since the 1990s there has been increasing awareness in the psychological community that psychology is changing: Globalization is changing the quality of psychological research. Psychologists have explicitly discussed the increasing internationalization of psychology and "international psychology."[62] The International Union for Psychological Science (IUPsyS) is stepping up efforts to foster international collaboration. A regularly published CD-ROM (Wedding and Stevens 2007) provides members with information on international contacts, member organizations and other resources relevant to in-

[59] A selection of only the most important and influential organizations is given.
[60] See (Draguns 2001); Luria cited in (Brandt 1970; Russell 1984).
[61] On the accessibility of foreign-language psychological literature, see also (Bauserman 1997).
[62] For example, (Lunt and Poortinga 1996; Fleishman 1999; Jing 2000; David and Buchanan 2003; Stevens and Gielen 2007).

ternational psychology.[63] Increasingly the World Wide Web is providing fora for international communication among psychologists. An outstanding example is XMCA, an e-mail discussion group sponsored by the Laboratory of Comparative Human Cognition at the University of California, San Diego.

Today we have the following picture. On the one hand, North America and Western Europe, in particular the US, continue to play a leading role in the production of psychological knowledge. This knowledge is exported all over the world; an increasing number of psychologists are trained to work within Western frameworks. On the other hand, Western theories and methods have created a tension with local traditions, concepts and needs.[64] This tension has led to new kinds of research: cross-cultural studies,[65] indigenous psychologies[66] and cultural psychology.[67] Internationalization amounts to the spread of mainstream (Western) paradigms and simultaneously to the growing interest in cultural variation.

Definitions and Ideals

International psychology can be defined as the sum total of "psychological knowledge and research obtained throughout the world," where psychology means the study of universal and local factors that determine "human behavior and experience" (Pawlik and Rosenzweig 2000, xxxi). There are three main features that qualify modern psychology as an international science: (1) the same paradigm is used in different countries; (2) psychologists are interested in cross-cultural problems; and (3) psychologists are becoming increasingly interested in the robustness of their results, that is, the degree to which experimental studies conducted in Western countries can be replicated elsewhere.

There is a growing understanding that if psychology is to become a rigorous human science, it has to be international. If it is not international—if it is not shared by all humans—it remains merely a Western science, which can only understand certain aspects of the human situation. Psychology has to avoid the charge of being, to borrow an expression from Heidegger, "the American interpretation of Americanism" (Heidegger 1977, 153).

The spread of psychology across the globe has brought about a re-evaluation of how psychological knowledge is produced. New methodological problems have arisen. For example, there is an opposition between current approaches to the study of cultural variation: the *cross-cultural* approach (which applies Western concepts to local conditions and investigates the limits of these concepts; this approach is supposed to lead to the identification of cultural and universal aspects of human behavior and cognition (Poortinga 1997; Keller et al. 2002); the *cultural*

[63]See also (Sexton and Misiak 1976; Sexton and Hogan 1992; Pawlik and Rosenzweig 2000; Stevens and Wedding 2004).

[64]See (Koch 1985; Graumann 1997; van Strien 1997; Jing 2000).

[65]See (Kagitçibasi 1987; Kagitçibasi and Berry 1989; Gergen et al. 1996).

[66]See (Enriquez 1992; Sinha 1997; Jing 2000; Yang and Hwang 2000; Kim 2001; Kim and Park 2004; Allwood and Berry 2006; Kim et al. 2006).

[67]See (Scribner and Cole 1981; LCHC 1983; Cole 1996; Cole et al. 1997).

approach (which studies behavior and cognition in the context of specific local activities (Cole 1996)); and the *indigenous* approach (which aims to derive psychological concepts and methods from local cultural practices (Enriquez 1992)). Some psychologists believe that the future of international psychology lies in the synthesis of the three approaches.[68]

The ideal of international psychology should be to identify in behavior and cognition what is innate, what arises in ontogeny as a result of uniform aspects of human experience, and what varies among cultures. A group of leading theoreticians has written that:

> […] methodological difficulties of culture-informed developmental research reflect to an important extent the absence of more precise and testable theories. Probably the most promising perspectives are those that will combine biological and cultural-contextual underpinnings of behavior. (Keller et al. 2002)

Similarly,

> […] cross-cultural studies can make an important contribution to the testing of such theories, providing data to help differentiate between species-wide processes and contextually bound variations in developmental patterns. (Poortinga 2005, 112)

Obstacles Toward the Internationalization of Psychology

On the way to internationalization, psychology faces some serious obstacles. Concepts in the natural sciences tend to be uniform, well-defined, and hence easily exportable to different cultural contexts. One major source for this uniformity is the uniformity of the natural world. Physical phenomena are essentially the same for an American, a Japanese and a Kenyan. By contrast, psychology as a human science deals with a subject—the human—that is considerably determined by cultural variation. A psychologist in Japan is likely to observe psychological phenomena that differ markedly from those that an American psychologist might observe. Hence cultural heterogeneity raises obstacles for the equilibration of psychological concepts. For example, American studies of *behavior* were rooted in the American culture of the first half of the twentieth century; Bowlby's *attachment* reflects a particular Western cultural understanding of the mother-infant relationship; Vygotsky's *zone of proximal development* reflects aspects of a collectivist Soviet culture, where children closely interacted with adults who were responsible for their *Bildung.*

Intercultural psychology depends on the equilibration of psychological concepts. Culturally specific phenomena must be identified and concepts that claim universality, but are limited in validity to a particular cultural domain, must be

[68] See (Cole 1992; Kagitçibasi 1992; Poortinga 1997; Sinha 1997).

modified. There are several reasons to believe that such equilibration will take place. First, general processes of globalization at the social level will create an increasingly shared cultural background. Second, the increasing interest in cultural approaches in psychology will help to disentangle what is culturally specific from what can be part of a general and universal psychological theory. In this project, the history of psychology, insofar as it closely scrutinizes the evolution of specific psychological concepts, can play a valuable role.

The Necessity of Really Global Psychology and Promising Signs

Psychology is by definition a science concerned with the study of human, not American or European, behavior and cognition. It is then inherently universal rather than parochial. If a psychology is only applicable to certain cultures, then it has failed in its aims. As other processes of globalization take place, and as a truly international culture emerges, psychologists are much better positioned to create a psychology that is general and universal, while at the same time accommodating, and even explaining, the range of cultural variation that is actually observed.

There are promising signs that global psychology is, however slowly, emerging. As George Mandler writes:

> One of the most salient aspects of [recent] advances is that they are occurring not just in the United States but also in Europe, Latin America, Japan, China and other countries with active psychological communities. It appears that psychology is developing a catholic consensus, an international paradigm that did not exist prior to the mid-twentieth century. (Mandler 2007, 245)

Moreover, we observe an increase in the number of papers co-authored by researchers from different parts of the world—irrefutable evidence of global cooperation. Electronic media serve as enabling technologies for international collaboration, and both their utilization and the possibilities they offer are only likely to increase. An authority on international psychology predicts that:

> In the foreseeable future, along with the globalization process and increase in international exchanges there will be more convergence in the structure and content of the study of behavior and consciousness, and more commonalities than differences may exist in international psychology. (Jing 2000, 581)

Although globalization is creating new human problems—such as the rapid growth of immigrant groups who are poorly assimilated into their new society; conflicts, armed or otherwise, that arise from inequalities in the distribution of wealth; and an increasing uncertainty throughout the life course (Hofäcker et al. 2006)—international psychology has the potential to help solve these problems. Areas of application include therapy that targets culturally specific attributes of post-traumatic stress disorder (Sack et al. 1997; Perilla et al. 2002; Pole et al. 2005); addressing the problem of culture shock (Ward et al. 2001); providing culturally appropriate counseling to refugees (Bemak et al. 2003; Blackwell 2005); facilitating conflict resolution in different cultural contexts (Sandole and van der Merwe 1993; Tinsley 1998); creating programs to address domestic violence and battered women syndrome around the world (Walker 1999); and developing culturally targeted models in organizational and work psychology (Aycan 2000). In fact, the need for such applications may itself constitute a force that advances global psychology.[69]

International psychology depends on an integration of cross-cultural and cultural psychology into the mainstream of psychology.[70] Ultimately this integration entails a complete assimilation; thus:

> Cross-cultural psychology will be shown to have succeeded when it disappears. For, when the whole field of psychology becomes truly international and genuinely intercultural—in other words, when it becomes truly a science of human behavior—cross-cultural psychology will have achieved its aims and become redundant. (Segall et al. 1998)

What International Psychology Owes to the Work of the Soviet Psychologists

Although the program of the Soviet psychologists failed as such, it served as a precursor to the international psychology that is emerging today, and contemporary psychology has incorporated, and sometimes transformed, concepts and ideas of the Soviets. The Soviet psychologists played an important role in recognizing the contribution of social and material factors to psychological functioning.[71] In particular, they drew attention to the development of higher mental functions, which are especially influenced by social and material factors.[72] Vygotsky's ideas about the role of language and social context for learning have been integrated in the new "explanation-based" paradigm of cognitive development (Goswami 2002, 513–514). Luria played a key role in the creation of neuropsychology, a paradigm that integrates psychology and the brain sciences. If psychology is going to develop along two divergent paths—one firmly rooted in the brain sciences and the other humanistic in character (Kagan 2006)—Luria must be recognized as a major contributor to both; to the first with his pioneering neuropsychological investigations

[69] Cf. (Jing 2000, 582). It is remarkable that the first international association of psychologists was the International Association of Applied Psychology. It was established in 1920 by Claparède and was initially called the International Association of Psychotechnics.

[70] As Michael Cole observes, although there have been significant recent advances in cultural psychology, much work remains to be done for its integration into a general paradigm (Cole 1995, 187).

[71] The Soviet psychologists derived this idea from Marx, but they were the first to show *how* one might demonstrate that human development depends on social and material factors.

[72] Cf. (Tomasello 1999, 163).

already in the late 1930s, and to the second with his famous essays on "romantic science." Vygotsky's cultural-historical theory and Luria's work in Uzbekistan became a lasting inspiration for cultural psychologists (Miller 1997).

Vygotsky had a vision of psychology as a unitary scientific enterprise that would explain cultural variation (Vygotsky 2006a). This vision was premature, and Vygotsky mistakenly believed that psychology needed a theoretical paradigm that would be developed top-down.[73] Contrary to Vygotsky's vision, international psychology is emerging piecemeal from research along many different lines. But psychology is becoming increasingly integrated as Vygotsky imagined it would (Vygotsky 2006a). It seems today that the international psychology Vygotsky envisioned is gradually taking shape.

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[73]Today an interesting attempt to unify psychology top-down is made by evolutionary psychologists, who rely substantially on cross-cultural research, see, for example, (Schmitt 2004; Tooby and Cosmides 2005). The viability of the evolutionary paradigm is now being hotly debated in the psychological community. Time will show how tenable the new paradigm is, but most participants of the debate agree that the only productive way for psychology to develop is through the integrated study of mind and behavior across different fields and disciplines, such as cognitive psychology, neuropsychology, social psychology, differential psychology, ethology and anthropology, see, for example, (Panksepp and Panksepp 2000).

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Chapter 27
The Global Diffusion of Nuclear Technology

Angelo Baracca

27.1 Introduction

Among the deep changes undergone by science and technology in their organizational forms, social and economic role, structure and contents during the World-War-II and post-war periods, the birth and diffusion of nuclear science and technology are probably among the most far-reaching and significant. Since the beginnings of nuclear technology, its intrinsic *dual-use*—and the associated military implications—have strongly influenced its development and role, with major consequences for international political and economic relations. The strong military implications of this technology unfortunately impede a thorough reconstruction and assessment of its history: several programs with military goals were (and still are) secret, sensitive information and documents are still classified, and much international commerce and interchange remains unregistered, if not illegal.

"Big Science" as a research model, which revolutionized post-war scientific and technical research, had its baptism in the "Manhattan Project," the wartime effort to design and build the first nuclear weapons. However, as nuclear science and technologies took off during the 1930s, local attitudes and conditions intertwined and produced original contributions, leaving different choices open. Since the very beginning of nuclear research, the practical exploitation of the enormous energy contained in the atomic nucleus had been one of the basic goals (Flügge 1939); further perspectives on technical applications played a fundamental role in shaping further choices.

It seems convenient to distinguish between *cultural* and *technical* aspects in the development of nuclear energy, since the early studies on the atomic nucleus tended to show greater effects by local influences, while the later works, beginning mainly from the 1940s, decisively shaped the structure and contents of nuclear science, thus deeply influencing the first aspect as well; in the particular political and economical context that resulted, nuclear technology became globalized.

27.2 "Romantic" Phase: Early Research and Diffusion Mechanisms

27.2.1 Deeply Innovative Features of Nuclear Science and Technology

If the birth of nuclear physics can be traced back to Rutherford's experiments (Rutherford 1911), which ascertained the concentration of the positive charge and mass at the center of the atom, the study of the internal composition and properties of the nucleus began in the early 1930s. It was not simply a transmission and development of the techniques developed and the results obtained in the Cavendish Laboratory under Rutherford's direction (the Rutherford-Geiger detector, Cockcroft and Walton's voltage multiplier, the splitting and transmutation of the nucleus, the discovery of the neutron): besides new techniques, deep structural changes on the economic and social levels boosted and transformed nuclear physics in the 1930s (Stuewer 1979).

The fact that during the war the program for the construction of a nuclear weapon was progressing, not only in the US, but also in Germany and Japan, France, the UK and the USSR—showed that, for both its scientific and technical bases, the time was ripe for such a development. In fact, the war was the launch pad for a spectacular leap in scientific and technical research, built on the recasting of these sectors that had begun over the previous decade (Battimelli et al. 1984). Roosevelt's "New Deal" was a strategy to recover from the post-1929 depression, an attempt to overcome the recurrent self-destructive overproduction crisis of the capitalist system, through a continuous renewal of industrial sectors and products. Such a strategy was reflected in the promotion of a new dynamics of the development, multiplication and specialization of scientific branches (Genuth 1987) in order to sustain continuous technical and productive innovation.[1]

Nuclear physics was one of the new fields in which this took place (Weiner 1970; Hansen and Stampen 1994), and also coincided with the growing scientific leadership of the US. Two techniques on both sides of the ocean, based respectively on cosmic rays and particle accelerators, contributed to the discovery of the elementary particles necessary for the physical understanding of nuclear structure and processes (1932: neutron, Chadwick, Cambridge; positron, Anderson, Caltech). It was Ernest O. Lawrence in the US who developed a new kind of managerial capability, soliciting huge funds for the innovative projects of his successive cyclotrons (Heilbron and Seidel 1989) during the worst phase of the economic recession, when the budget for research and higher education suffered big cuts (Weiner 1972). Lawrence succeeded in convincing philanthropic societies, as well as electric and medical companies, that the new knowledge in nuclear physics was worth supporting in view of its innovative applications. However, he was interested above all in building more and more powerful machines, foreshadowing the spirit and characters of Big Science (Galison and Hevly 1992; Gemelli 2001).

[1] For example, (Conkin 1967; Fraser and Gerstle 1989).

In this connection, it is important for our aims to remark that Big Science was not a necessary choice imposed by the very development of the organization and method of scientific research, necessitated by the growing complexity of the problems under study; on the contrary, these early post-war developments showed the simultaneous presence of diverging scientific attitudes, which we could denote as “Big” and “Little” (or “Intermediate”) science, and sometimes as their clash (Baracca 1993).[2] On the other hand, the final victory of the Big Science approach also deeply influenced the kind of scientific research results and interpretations, not to mention technical applications concerning the atomic nucleus. In particular, Lawrence’s race toward more powerful cyclotrons became a goal in itself, such that he devoted much less attention to the experimental equipment and method, ultimately missing fundamental discoveries like the artificial radioactivity Cockcroft and Walton found using a less powerful and sophisticated accelerator.

27.2.2 Early Local Schools and Approaches

With regard to local factors, a great number of instances can be mentioned (Malley 1979). While particle accelerators became the new frontier of nuclear research, in countries that had no chance for building such machines, fundamental results were obtained with alternative techniques: in fact, this is the way the decisive results for military applications were achieved. One can mention the Joliot-Curie laboratory in France (Pinault 2000), and the studies on slow neutrons obtained with the emulsions technique by the Fermi group in Rome (Segré 1979; De Maria 1999), although their correct interpretation[3] was provided some years later by the group of Hahn and Strassmann, specifically by Lise Meitner.[4] A second instance is given by Japan, where a markedly national approach to physics was adopted, rooted in traditional philosophy, lacking applicative aims but emerging as a forerunner of subsequent approaches and results (Brown et al. 1980). For instance, Yuakawa’s meson hypothesis (1936) was not merely the conception of a particle mediating nuclear forces: the meson was rather the central element of a more complex and

[2]Actually, it was one of the outstanding nuclear physicists of the 1930s, Merle Tuve (Lawrence’s contemporary, fellow-townsman and classmate), working at the Carnegie Institution in Washington, who refused to join the Manhattan Project, developing during wartime the proximity fuse instead. But after the war he openly opposed Big Science, ultimately “[leaving] nuclear physics when it turned from a sport into a business.” One may add that European physicists visiting Lawrence’s Berkeley laboratory during the late 1930s; other scientists (like the biologist Jacque Monod for other laboratories in 1946) felt similarly perplexed about pursuing scientific goals in the face of such dimensions and levels of organization. See, for example, (Heilbron and Seidel 1989, 238–252, 350–352; Gaudillière 2002b).

[3]Although Fermi correctly interpreted most of the results of his group, only the assumption of transuranic elements was not right, but neither was it fully wrong, as was shown later.

[4]See (Meitner and Frisch 1939; Frisch 1979; Lewin Sime 1996; Sánchez Ron 2000, 245 ff.). This circumstance offers occasion to remark on the monopoly of male scientists in the development and transmission of scientific knowledge. It would be interesting to investigate the possible consequences of this factor on the kinds of fields, knowledge and applications that were developed, but that goes beyond the scope of this paper.

coherent philosophical framework (Brown and Hoddeson 1983). What is more, the Japanese case confirms the absence of a strict correlation between the use of particle accelerators and the development of research structures organizing Big Science: cyclotrons were in fact built in Japan during the 1930s, but research proceeded in small groups.

27.3 The War and the Manhattan Project: Diffusion or Secrecy of Knowledge?

27.3.1 Highly Coordinated Scientific Research under Military Rule

I will not discuss the developments of nuclear physics during the war. The Manhattan Project is too complex to be analyzed here; detailed studies have been published since the documents were declassified (Pringle and Spigelman 1982; Rhodes 1986). In contrast, the uranium projects in Germany and Japan still leave many aspects to be clarified.[5] The theatre of war displayed the immense contribution that science-based technologies—such as the atom bomb, proximity fuses, guided missiles and radar—could make to national defense (Kevles 1978). The conflict also spawned entirely new fields such as operations research, which applied statistical methods to improve the efficiency of resource allocation in both military and industrial systems (Fortun and Schweber 1993; Krige 2006a, chap. 8).

An exceptional feature was introduced in wartime in scientific and technical research, which would subsequently characterize the work of a large part of the scientific community, especially in nuclear physics: i.e. *secrecy*, which appears as the opposite of the very spirit of scientific investigation, or at least of its stereotype. For the first time, an entire scientific community was put together to work on a unique project (the Manhattan Project), with extremely fragmented tasks, under strict *military* control. One could pose the problem of how war (in general, military research) may affect the development, orientation and diffusion of knowledge in general.[6]

It must be stressed that the first large-scale application of nuclear technology was military: the "Fermi pile," the first nuclear reactor for controlled chain reaction, was not conceived to produce power, but served as a central step in the Manhattan Project. Its purpose, in fact, was the experimental proof of the feasibility of the chain reaction, and—after plutonium was discovered by Seaborg and collaborators in 1941—to find a way to produce it in large quantities, while the process for enriching uranium was in progress. In fact, for many years after the war, only military nuclear reactors were built. Since the beginning, therefore, the *dual-use* nature of nuclear technology appeared as a basic, historically

[5]For the Nazi uranium project, see (Goudsmit 1983; Walker 1992, 1995; Bernstein 1996; Rose 1998). For the Japanese project (Shapley 1978; Grunden 2005; Nagase-Reimer et al. 2005).

[6]In the case of nuclear technology, one can conclude that the bomb would have been built in any case. Without the war, however, it could have required perhaps twenty years, during which research in the field could have led to somewhat different choices, developments and results.

novel feature of the diffusion of science-based technology, and of every subsequent development: in Oppenheimer's famous words, a kind of "original sin."

27.4 After the War: Monopoly or International Control?

The atomic bomb played a determinant role in post-war international politics. This was a crucial period for setting out the nature and mechanisms of transmitting and controlling the new technology in its civilian and military use: several options were actually open, and the choices and changes were determined by political and economic factors. The US trusted in a long-term monopoly on nuclear weapons. Two basic conceptions stood in opposition to each other. Several influential figures advocated international control, shared in particular, but not only, with the Soviets (back in 1944 Bohr had strongly supported this solution, incurring Churchill's denial and harsh criticism). The final failure of the proposal for international control of nuclear technology, and the elimination of nuclear weapons, was the rejection by the Soviets of the "Baruch Plan," presented by the US at the UN in 1946 (Hewlett and Anderson 1962; Smith 1965; Robinson 2004).[7]

Just one month later, the US Congress approved the "McMahon Act" on the control and management of nuclear technology, which established a rigid policy of secrecy on nuclear matters, especially military ones. Such a rigid structure was not appreciated by the advocates of the development of a private industrial sector: indeed, this legislation was changed radically in the 1950s.[8] The United States based its security policy on its sole possession of the scientific, technological and material basis of atomic energy (Herken 1980). In hindsight, such a trust in a long-lasting monopoly on nuclear weapons appears superficial. As a matter of fact, it was broken by the 1949 Soviet nuclear test (Holloway 1994), which inaugurated the process of (military) nuclear proliferation. The Cold War had begun and the nuclear arms race took off.[9]

[7]A Wall Street businessman charged by Truman with the mission of presenting the proposal to the UN, Baruch modified the plan and presented it with conditions that were not acceptable to the Soviets. The complete text of the plan can be found at: www.atomicarchive.com/Docs/Deterrence/BaruchPlan.shtml. As a subsequent authoritative pledge for "full mutual openness" in the flow of atomic information as a means of reducing "distrust and anxiety" between the superpowers, it is worth recalling Niels Bohr's famous *Open Letter to the United Nations* of June 1950 (Bohr 1950).

[8]It is noteworthy that at the end of the 1940s, the first nuclear engineering technical schools were established and open to foreign students (Oak Ridge, MIT, Berkeley). At the same time a work was published about the Allied World War II effort to develop the atomic bomb, the Manhattan Project (Smyth 1945); also the Field Information Agency, Technical (FIAT) Report was written (Bothe and Flügge 1948).

[9]The subsequent steps of nuclear proliferation have been reconstructed; starting points include (Gowing and Arnold 1974; Frisch 1979; Lewis and Xue 1988; Cohen 1998; Bendjebbar 2000; Perkovich 2001). For an overview, see (Bundy 1988; Reed and Stillman 2009).

27.4.1 Involvement of Scientists in Political Decisions: The New Role of Science in International Relations

Nuclear armaments also played a leading role in the profound post-war transformation of scientists' role in political advice and decisions. Due to the primary role played in wartime, scientists, even those in esoteric fields such as mathematics and theoretical physics, along with engineers, were considered an essential national and strategic asset, and were increasingly integrated into foreign affairs. Vannevar Bush was an enthusiastic proponent of this idea (Bush 1945). Now scientists became essential not only for the development and security of the nation, but also in its dealings with other states, in its efforts to project and consolidate its power in the international domain and build a stable world order.[10] During the war scientists had been appointed, together with politicians, to boards charged with proposing the decisions to be made in the use of nuclear weapons, and after the war those involved in their development (think, for instance, of the role played in the US by Edward Teller, or by other scientists in the USSR), proposed nuclear strategies and international negotiations about their control (Jacobson and Stein 1966; Barth 1998). Especially in nuclear matters and in strategic decisions, scientists assumed a role as experts in presidential decision-making.[11]

The increasing involvement of scientists in political decisions grew in parallel with the increasing role of science and technology as fundamental strategic factors for economic development, national security and international relations. In the first fifteen years after the war, science and technology became an affair of the state, and the governments in the Western industrialized countries implemented formal policies that matched science with national priorities.[12]

27.5 The Turning Point: "Atoms for Peace," the Supermarket of (*Dual-Use*) Nuclear Technology

Not until after the Soviets had exploded their own nuclear weapons in 1949 and 1950 did "Atoms for Peace" become a serious topic of discussion. This revolution in the politics of diffusion of nuclear technology took place in the 1950s, preceded by other basic developments.

27.5.1 Naval Nuclear Propulsion

The federal government had invested huge funds in the development of military nuclear technology, making the new sector ripe for more applications. In particular, besides military nuclear reactors for the production of plutonium, there were proposals for nuclear ships, locomotives, automobiles and aircraft. Only

[10] See (Kevles 1990a; De Cerreño and Keynan 1998; Manzione 2000).
[11] See (Gilpin 1962; Jacobson and Stein 1966; Jasanoff 1990; Doel 1997; Herken 2000; Schweber 2000).
[12] See (Salomon 1977; Smith 1990; Skolnikoff 1993; Krige and Barth 2006).

marine propulsion was successful: the reactors developed to this end played a fundamental role in subsequent civil applications. The successful development of a nuclear propulsion plant by a group of scientists and engineers at the Naval Reactors Branch of the US Atomic Energy Commission, AEC (1953), led to the construction of the *Nautilus* (1955), the world's first operational nuclear-powered submarine. The subsequent failure of other models led to the selection of the PWR (Pressurized Water Reactor) as the standard US naval reactor type. In the US, a single series of standardized designs was built by both Westinghouse and General Electric; the British company Rolls Royce built similar units for Royal Navy submarines.

Soviet work on nuclear propulsion reactors began in the early 1950s at the Institute of Physics and Power Engineering (Obninsk): the first Soviet propulsion reactor began operational testing in 1956. Aside from a few test designs, the Soviet Navy, too, opted for light-water reactors.

Nuclear propulsion has been practically limited to military ships (submarines and aircraft carriers), with the exception of three freighters and the Soviet ice-breakers, and the German nuclear research ship *Otto Hahn* (1968). The introduction of nuclear submarines entailed a deep change in military strategies, in particular with respect to nuclear weapons, especially when the introduction of ballistic missiles (see below) made land-based weapons vulnerable to a pre-emptive attack. At the end of the Cold War there were over 400 nuclear-powered submarines operational or under construction: since many ships use more than one reactor, the total number of military reactors built to date is larger than that of civilian power reactors (439 working at present). From my point of view, it is important to note that the American type of nuclear reactors developed for naval propulsion determined the models that were subsequently adopted for civilian power reactors.

27.5.2 The Development of the Industrial Military Complex

Another aspect was of instrumental importance to the further development and diffusion of nuclear technology and its features: the establishment in the United States of a huge *industrial military complex*. The main companies had collaborated strictly to realize military projects, and established deep ties with political power. However, the military control exerted on research activity during the war could not continue in peaceful times: the majority of scientists who had worked in the Manhattan Project returned to their universities and institutions. The need for the government to keep up cooperation with the scientific community useful for the military programs took other forms. The most direct was the establishment of a huge sector of research devoted entirely to military research, which kept close ties with the main industries. Besides the three main National Laboratories devoted mainly to nuclear armaments,[13] a myriad of smaller centers grew up in

[13]Los Alamos, Sandia and Lawrence Livermore: note that the last of these was established in 1952 by the above-mentioned inventor of the cyclotron, Ernest O. Lawrence, although the decisive force behind this project was Edward Teller.

the US.[14] The overall costs of the whole system of nuclear armaments (warheads, launchers, alert and control systems, dismantlement, nuclear wastes and so forth) is obviously unknown, but as the main item of national defense is undoubtedly around several trillion dollars, one of the largest items of the US federal government expenses (Schwartz 1998a; Burr 2009). The very fact that a large part of scientific and technical research was developed after the war in *military laboratories* or for military applications, absorbing a very large part of the total budgets for research and design (R&D), is a factor whose relevance and consequences seem far from being fully appreciated, let alone investigated.[15] In this chapter I will discuss at least some of the main consequences for the case of nuclear technology.

In the USSR, too, a huge complex was established for the development of nuclear and other armaments (suffice to recall the "secret cities"[16]): the main difference with respect to the US probably being that, as the whole industrial system belonged to the state, it was a purer *military system*. In my opinion, this had major consequences, not only for nuclear technology, but probably for the entire Soviet economy. In fact, the development of this technology in the USSR did not propel the growth of the economy, but acted rather as a dead weight, whose negative role grew more and more until the final collapse.

27.5.3 Promotion and Diffusion of "Civilian" Nuclear Technology

With huge federal investments, the development of nuclear reactors and all the parts of the nuclear fuel cycle had prepared the ground for the commercial launch of the technology. We have seen that the main American companies were engaged in the development of power reactors for naval propulsion. The same firms could therefore rely on these same models for the design of commercial thermal light-water reactors: pressurized water reactors (PWR) by Westinghouse; boiling water reactors (BWR) by General Electric. The adoption of these military prototypes for civilian use was not without consequences. Many military reactors work with highly enriched uranium, and require peculiar properties for their special conditions of operation and the specific needs of the militaries: they appear to be far from safe, as is evinced in the higher frequency of accidents in nuclear submarines.[17] This poses the question as to whether the development of these same models for civilian use has proved to offer the best safety standards.

Actually, the first power reactor was developed in the USSR in 1954 in Obninsk. But it was in the US that the opportunity for an international diffusion of nuclear technology for peaceful uses was seized, for both commercial and po-

[14] See (Leslie 1993; Dahan and Pestre 2004); see also an updated list of military labs in (Schwartz 1998b).

[15] See, for example, (Gomatan and Ellison 1986).

[16] See, for instance: www.pbs.org/wgbh/pages/frontline/shows/russia/arsenal/structure.html.

[17] See, for instance, (Olgaard 1996). For a list of sunken nuclear submarines, see: en.wikipedia.org/wiki/List_of_sunken_nuclear_submarines; for the US: www.lutins.org/nukes.html#subs; for the USSR/Russia: spb.org.ru/bellona/ehome/russia/nfl/nfl8.htm.

litical aims. As such, around the mid-1950s—reversing the politics of absolute secrecy chosen after the war—the diffusion of nuclear technology turned into a programmed political and economic operation. This campaign was promoted by President Eisenhower's "Atoms for Peace" speech before the General Assembly of the United Nations (8 December 1953), and launched with the 1955 Geneva Conference with the same name (with 25,000 participants).

In fact, formal international cooperation in atomic science had to wait for the creation of the International Atomic Energy Agency (IAEA) in 1957, along with its system of safeguards to prevent the military use of atomic energy. Atomic scientists were among the last fields of expertise to obtain a UN Specialized Agency dedicated to their field.

One must recall that around 1950—after the Berlin Blockade (1948–49) and the birth of the Atlantic Alliance (1949)—a new phase of the Cold War had begun, with military encounters between the two blocks, in which the danger of the use of nuclear arms appeared quite concrete:[18] suffice to recall the 1962 Cuba "missile crisis" (May and Zelikow 2002). Moreover, thermonuclear weapons were developed (the H-bomb), in a surprising sequence: the test by the US in November 1952 of a substantially stationary device (Mike Test), was followed in an astonishingly short time (August 1953) by the Soviet explosion of a more or less real bomb (Holloway 1994), while the US did not follow with a real bomb until March 1954.

The rhetoric in Eisenhower's speech can be contextualized and marks a peculiar factor in the global diffusion of nuclear technology. Recognizing that "a danger exists in the world […] shared by all," and "the expenditure of vast sums for weapons and systems of defense can[not] guarantee absolute safety for the cities and citizens of any nation," he proposed "to help us move out of the dark chamber of horrors into the light, to find a way by which the minds of men, the hopes of men, the souls of men everywhere, can move forward toward peace and happiness and well being." Nuclear technology must therefore "be put into the hands of those who will know how to strip its military casing and adapt it to the arts of peace": in this sense, "a special purpose would be to provide abundant electrical energy in the power-starved areas of the world," beginning at the same time "to diminish the potential destructive power of the world's atomic stockpiles."[19] In 1954 the secrecy dictated by the McMahon Act was overturned by the Atomic Energy Act, which explicitly allowed the transmission to friendly countries of nuclear knowledge and materials for peaceful uses.

27.5.4 Atoms for Peace, Dual-Use, Proliferation: An Assessment

An analysis of the features of the "Atoms for Peace" campaign is probably the main source for understanding the mechanisms of global diffusion of nuclear technology,

[18] As General McArthur explicitly requested during the Korean War, 1950–53; nevertheless, massive use of napalm caused more than one million victims and the destruction of practically all North Korean cities.

[19] See http://www.atomicarchive.com/Docs/Deterrence/Atomsforpeace.shtml.

the role of military and civilian applications, the relationships between center and peripheries, knowledge restrictions deriving from secrecy, industrial protection, and so on. I am necessarily compelled to restrict this analysis to certain aspects.

The basic economic and commercial interests were supported by ideological arguments. An emblematic expression of the latter are the words uttered in 1954 by Lewis Strauss, Lilienthal's successor as Director of the AEC:

> It is not too much to expect that our children will enjoy electrical energy too cheap to meter, will know of great periodic regional famines only as a matter of history, will travel effortlessly over the seas and through the air with a minimum of danger and at great speeds, and will experience a life-span far longer than ours, as disease yields and man comes to understand what causes him to age. This is the forecast for an age of peace. (Hilgartner et al. 1982, 44)

The international campaign that was promoted was impressive, but one may legitimately question its alleged *peaceful* purpose, for more than one reason. It was a truly massive political and economic offensive, aimed to attract neutral or irresolute countries in the Western sphere with huge investments for the purpose of reinforcing a belt of Western-oriented countries around the Soviet Union, and demonstrating the superiority of capitalist technology.[20]

For such goals, the campaign relied, presumably in deliberately ambiguous terms, on the intrinsic *dual-use* feature of nuclear technology, implicitly or explicitly feeding the illusion that any country that adopted civilian nuclear programs could ultimately acquire nuclear arms, and consequently an overwhelming superiority in its regional context. Having a nuclear capability of some kind was at once a guarantee of international recognition, a symbol of modernity for leaders and their allies among national elites, a bargaining chip with which to affirm national autonomy and to protect national sovereignty and national political agendas, and potentially an invaluable addition to military strength.[21]

As a matter of fact, many countries have, at least presumably, developed secret nuclear military programs (Brazil, Argentina, Sweden, Switzerland,[22] South Africa, India, Pakistan, Iraq, Iran, Libya, Egypt, Syria, and so on). In some cases these programs were successful[23] (India, 1974, 1998; South Africa, 1975–1979; Pakistan, 1998; North Korea, 2006), in others they led to the acquisition of the

[20] For general references, see (Kollert 1994; Medhurst 1997; Lorentz 2001; Lavoy 2003; Krige 2006b).

[21] For general references see, for example, (Ogilvie-White 1996; Sagan 1996).

[22] In the words of Rob Edwards (1996): "Switzerland maintained the option to develop its own nuclear weapons until 1988, according to a detailed account released by the Swiss government. The country's atomic bomb program, which ran for forty-three years, included a secret stockpile of uranium, an attempt to buy weapons-grade plutonium and plans for 400 nuclear warheads."

[23] Some basic references are the following. For India: (Abraham 1998; Perkovich 2001). For South Africa: (Albright 1994; Liberman 2001; Purkitt and Burgess 2005, chap. 3). For Pakistan: (Ahmed 1999). Some peculiar mechanisms underlying the processes of nuclear proliferation can be understood by keeping in mind that for purely political reasons—a stable white South

complete nuclear cycle, probably not too far from the realization of a weapon: Brazil, for instance, has carried out the large-scale process of uranium enrichment without suffering the strong objections raised against Iran.[24] In fact, the possession of nuclear reactors is a necessary step to arrive at nuclear weapons. From the outset Eisenhower was well aware of this danger, and in his speech he proposed the establishment of the International Atomic Energy Agency, devoted to the control of the peaceful use of nuclear technology (as mentioned, the IAEA took up its work in 1957).

Moreover, the "Atoms for Peace" campaign did not limit nuclear weapons at all: under the Eisenhower presidency the American stockpile grew from 10,000 to 20,000 warheads (the Soviet total was one tenth of this number). In addition, in 1953 the US adopted a new nuclear strategy that placed nuclear armaments on the same footing as other weapons: it was substantially the first-use doctrine, which Washington has never abandoned.[25]

27.5.5 Diffusion of Nuclear Technology

The diffusion mechanisms of civilian nuclear programs, although based on almost standard designs, are difficult to synthesize in general terms, since they often followed specific local patterns in each country[26] (political, economic, technical conditions, specific ambitions, and so on).

In general terms, the diffusion of nuclear technology was marked by a peculiar relationship between the center and the peripheries: locally available knowledge and resources were promoted, yet strong limitations were also imposed since the American companies maintained their control over the basic technology. The United States led the process of international diffusion, dictated the conditions, and controlled its dynamics and basic processes, in particular uranium enrichment: scant space was left to other Western countries. A limited market was conquered by the Canadian natural-uranium reactor (Candu), designed precisely for getting round the enrichment process, although it offers advantages for proliferation programs due to higher plutonium production (India, for instance, has bought such reactors). The nuclear industries of some countries have done business with nuclear technology, also collaborating in military programs (like Israel, Germany

Africa as a barrier against spreading Marxism in Africa, and Pakistani help against the Soviet war in Afghanistan, respectively—the Department of State was willing to blur intelligence on the military programs in the two countries, and the support they were receiving from several countries. See, for example, (Gallucci 2005); cited in (Krige 2006b, 12 and fn. 32).

[24] On Brazil, see (Palmer and Milhollin 2004). An updated and comprehensive overview is offered in (Feldman 2010).

[25] A major "black hole" is the development of nuclear technology and armaments in Israel, which without doubt was strongly supported by foreign collaboration, but still presents deep unclarified aspects (Cohen 1998; Gerlini 2010).

[26] Two international workshops on these aspects were held recently in Barcelona, Spain, at the University Pompeu Fabra: A Comparative Study of European Energy Programs, 5–6 December 2008; and A Comparative Study of European Nuclear Energy Programs from the 1940s until the 1970s, 3–5 December 2009.

and Argentina with South Africa;[27] France and Italy, among others, with Iraq). Only France subsequently achieved technical and economic autonomy in the field when it chose to base its electric power production on nuclear plants, relying on a standardized design: notwithstanding the unique role of the state, one must point out that the alleged efficiency and economy of the French energy system is largely questionable, basically because of the rigidity of nuclear technology.[28]

For the Soviet Union the situation was completely different, since the diffusion of nuclear technology was not supported by profit mechanisms. Since the beginning Russia had a real need for electric power, and nuclear energy truly was seen as a possible solution: furthermore, some scientists saw an opportunity to work not primarily for military but for civilian uses, and the government, too, saw an opportunity to demonstrate to the world its peaceful ambitions. Moreover, the Soviet strategies for the diffusion of nuclear technology seem to have been quite different from the American ones. The Soviet Union, in fact, never allowed the countries in its sphere of influence to acquire, or even control, nuclear weapons (the cooperation with China was very cautious and was broken off at the first sign of disagreement).

27.6 The Landscape Becomes more Complicated: Other Incentives, New Fields

This is obviously not the place to go through all the mechanisms of diffusion of military nuclear technology. A very important aspect that cannot be tackled here was, and still is, the development of the whole system of nuclear armaments of increasing complexity and much higher cost than the warheads alone: from launchers, to warning systems and satellites, control systems, and so on.

27.6.1 One More Leap: The Shock of Sputnik

Precisely the early development of ballistic missiles was the cause for a strong acceleration in nuclear research and development. The launch in 1957 of the first Soviet artificial satellite, the *Sputnik*, came as a bolt from the blue (McDougall 1985): it was a tremendous shock for American public opinion and the political establishment, representing the threat that the Soviet system really could overcome

[27]For a perspective from those involved in building the South African bomb, see (Steyn et al. 2003).

[28]See (Schneider 2009; Schneider et al. 2009). The power of nuclear plants cannot be easily regulated: in order to cope with the peak demand for electric power, France produces a surplus of electricity, which in standard conditions it sells at very low prices, at the cost of inefficiencies and waste; under exceptional weather conditions it purchases the extra power it needs at high prices. One should further add a point that is anything but marginal for an evaluation of nuclear technology: since nuclear plants produce only electric power, which is generally less than 20% of total final energy consumption, France is no less dependent on oil than other less “nuclearized” countries.

the capitalist one.[29] The reaction to this shock produced a huge effort in the American research, technical, and education systems to face the perceived danger. Between 1957 and 1967 federal research and development expenditures nearly quadrupled, reaching almost \$15 billion (Kevles 1990b, xviii).[30] Without a doubt, this acceleration had deep consequences on the development and diffusion of new knowledge and technologies.

27.6.2 Foreign Science Politics and New Fields Induced by Nuclear Technology

One more aspect has played a large role in inducing the development of other scientific and technical changes, derived from or connected with nuclear technology. As remarked above, the kind of direct control exerted by the military on research activity in the US during the war could not continue in peaceful times. However the political and military establishment could not renounce the irreplaceable contribution of the scientific community. The solution was twofold. I have already discussed the creation of large laboratories devoted exclusively to military research, and scientists' appointment as political advisors or as members of Commissions: the role played for instance by the "Jason Division"[31] can hardly be underestimated (Shapley 1973).

But a more subtle endeavor took place as well, which seems more meaningful for the mechanisms being studied. The premise was that "the scientists of this nation be kept currently aware of the latest advances of modern technology, in whatever nation these may occur" (Berkner 1950)[32]; i.e. that the United States should never fail to appreciate an intellectual potential, in any country, that can produce fundamental results important for national welfare and security: such results must be integrated into the American system in a quick and continuous way. This concept grew along with the strategy of using science and technology in the projection of American power abroad, as happened in the clearest, although very subtle, way in the construction of a scientific American hegemony in the

[29]The 1955 Geneva "Atoms for Peace" conference had already shown to the most attentive people the high level already reached by the Soviet nuclear scientists. In 1954 the Soviet Union produced about twice as many Ph.D.s in the sciences as did the United States, probably of comparable quality.

[30]See also (Killian 1977; Dennis 1994; Krige 2000).

[31]This elitist group of scientists (named after the mythical Greek hero), including several Nobel laureates, was created in 1959. It meets every summer and freely elaborates on problems related to national security, defense and arms control, posed by the Pentagon, the Department of Energy and other federal agencies. Their reports, most of them classified, often directly influence national policy. The role of the Jason Division was particularly remarkable under Defense Secretary Robert McNamara, when its suggestions determined military decisions during the Vietnam war, but it is still influencing basic decisions about nuclear armaments.

[32]See (Anonymous 1950). For more details on the Berkner Report, see (Needell 2000; Miller 2001).

post-war reconstruction of science in Europe.[33] International scientific exchange (in particular in physics) was an instrument in the intellectual and cultural Cold War abroad.

In this context, a stealthier project gradually emerged, of encouraging the development of new branches whose perspectives of military application were quite distant, so that truly free theoretical research could be performed: no doubt the results in such fields would help in designing new and better armaments, but this would take a long time, allowing the militaries to gradually transfer the sensitive results into the zone of secrecy:

> Even if major scientific discoveries of economic and military importance were made [in Europe], America would be far more capable of taking advantage of them. (Krige 2006a, 12)

Under such conceptions, nuclear research itself underwent a process of institutionalization and open research in less sensitive sectors, which in any case provided more or less indirect support to the military activity in the special laboratories. Moreover, the physicists were particularly attracted by the new fields opening up that appeared even more stimulating. It was in fact acknowledged that, fortunately, there were fields of activity relevant to the AEC in which secrecy could, and must, be given up, since the possibility of immediate military application was too small in comparison with the need for further, open investigation. High-energy physics was an example of such a field, and was actually liberally financed.

Moreover, this choice also allowed the exploitation of scientific and intellectual potentials in foreign countries. The United States actually contributed to promoting advanced research in these fields in foreign countries, with the investment of local funds and resources.[34] The best-known case is probably the international laboratory CERN in Geneva (Hermann et al. 1987). The US played a decisive role in the proposal and establishment of CERN. As a matter of fact, a pathbreaking intervention was made in June 1950 by the American physicist Isidor Isaac Rabi, as a member of the US delegation to the UNESCO meeting in Florence (Jungk 1986; Krige 2004, 2005). He had an enabling resolution passed—after authorization by the US State Department and consultation with some European physicists—calling for the establishment of regional research centers grouping together several countries, like France, West Germany and Italy.[35] It was stressed that these centers

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[33]See (Doel 1997, 220; Krige 2006a). Needless to say, at least the most sensitive personalities acutely felt the threat to European culture and values, even the invasion of the deepest layers of the psyche (somebody spoke of the "Coca-Colonization"), the film director Wim Wenders called it "the colonization of the European subconscious" (Wagnleitner 1994, xii).

[34]A comprehensive analysis is undertaken in (Krige 2006a).

[35]Of course, helping rebuild European physics was not without risks: there were fears of a resurgence of German militarism and nationalism, and there were worries of security leaks to the Soviet Union. For an overview of the German problem see, for instance (Krige 2006a, chap. 2). The final solution came with the NATO treaty, and on the scientific plane with the establishment of CERN.

would produce "creative work on behalf of peace," thereby "saving Western civilization."[36] By pooling their human and financial resources, member nations could acquire the expensive instruments of modern research that they could not afford alone. As for the fields that ought to be explored at such centers, Rabi specifically mentioned physics, biology and computing, with accelerator physics as the initial priority. Europeans were encouraged to develop advanced research in *unclassified* high-energy physics. It must be stressed that several European physicists originally interpreted Rabi's resolution as suggesting that the laboratory build both an accelerator and a reactor for low-energy nuclear physics,[37] but Rabi clarified in the discussion the opportunity of foregoing a nuclear reactor at CERN. In 1954 the first Director of CERN was Felix Bloch, who came from the University of Stanford.

These premises help in understanding the leading role of, and financial support for, high-energy physics in the development of physical research in Europe and other countries in the following years.[38] However, high-energy physics is only one of many cases. A second important case is given by the research on controlled nuclear fusion (Bromberg 1982).[39] Widely hailed as a potential shortcut to cheap electric power, after half a century this technique is still far from accomplishing this requirement, but has been institutionalized as an unclassified field, absorbing huge funds and resources, and developed in several countries.[40]

A specific remark is in order, once again, regarding the mechanisms of diffusion in the Soviet Union, where these same choices were repeated, but did not act as an impetus for development and economy in state industry or the satellite Socialist states, becoming in many cases more of a dead weight than an advantage. The mechanisms for diffusing nuclear technology are therefore strongly dependent on the economic and social environment and on local conditions.

27.7 The Establishment and Implementation (or Violation) of the Non-Proliferation Regime

The problems posed by the dual-use nature of nuclear technology increased as ever more countries went nuclear (Great Britain in 1952; France and Israel in 1960; China in 1964), and the technology spread commercially, posing a growing need for an international control regime on its use and transfer. This led the superpowers to negotiate the Nuclear Non-Proliferation Treaty (NPT), which came into force

[36] Reservations have been raised about the purely peaceful implications of the research performed and the results obtained at CERN. See, for example, (Grinevald et al. 1984).
[37] See, for example, (Krige 2006a, 60 ff.).
[38] As a personal recollection, in Italy fields with more applicative potentialities, such as solid-state physics, were strongly discriminated against in post-war decades in favour of high-energy physics. A critical sociological and methodological analysis of research organization and practice in this field up to the 1970s was performed in (Baracca and Bergia 1975).
[39] For examples of other sectors see, for example, (Forman 1987) on quantum electronics, and (Fortun and Schweber 1993) on operations research.
[40] As concerns its possible military implications see, for example, (Gillette 1975).

in 1970, and in the following years achieved the compliance of the large majority of states, with a few exceptions, in particular Israel, India and Pakistan, which subsequently went nuclear outside the proliferation regime. Some non-nuclear states that had developed secret military projects presumably abandoned them just before signing the NPT (which in any case allows withdrawal at three-months' notice, as was the case for North Korea in 2003).[41]

The growing worries about spreading military nuclear proliferation led US President Jimmy Carter (a former nuclear engineer) to radical decisions in the 1970s—even at variance with sectors of his own administration—in order to try to put an end to plutonium production: he therefore stopped both the reprocessing of exhausted nuclear fuel, by adopting a once-through nuclear fuel option, and the development of fast nuclear reactors.[42] In the meantime France was making radical political decisions, withdrawing from NATO and developing its own *force de frappe*: in this context it remained the only country to develop an ambitious program of fast plutonium reactors[43] (with initial participation by Germany and Italy), which recently came to an end with the final shut-down of *Superphoenix* (1997).

Between the late 1970s and the early 1980s the problem of *tactical*[44] warheads deployed in Europe erupted:[45] the so-called "Euromissiles crisis" once more brought the threat of a nuclear war closer (Podvig 2008) and unleashed a strong peace movement explicitly demanding nuclear disarmament (Evangelista 1999). The final solution to the crisis was provided by the first historical agreement on a reduction of nuclear armaments, the INF (Intermediate Nuclear Forces) Treaty, signed in 1987 by Presidents Gorbachev and Reagan, which imposed the removal of all tactical nuclear weapons deployed on intermediate-range missiles.[46]

[41] Actually, the NPT is quite an asymmetrical treaty, preventing non-nuclear states from going nuclear through an international system of inspections and safeguards performed by the IAEA, but not providing stringent measures to impose nuclear disarmament on nuclear states. Such an asymmetry between "haves" and "have-nots," and the subsequent enduring polemics, have prevented the quinquennial Revision Conferences of the NPT from achieving substantial results on the path toward the total elimination of nuclear armaments.

[42] Only recently were the documents related to the Carter Administration declassified, so full analyses will appear in the coming years. In the meantime, see a detailed preliminary analysis in (Tiseo 2009); moreover, Joseph Nye, the president's advisor on nuclear matters (Nye 1981). See also (Donnelly 1979; Rana 1980; Potter 1982; Barrow 1998).

[43] At present Russia, India and Japan hold fast reactors programs for the future, see (Cochran et al. 2010); India's program, in particular, raises concerns of military proliferation, see (Ramana 2010).

[44] The distinction between strategic and tactical nuclear weapons is neither official nor accepted by all states (the USSR/Russia prefers to refer instead to sub-strategic weapons). The latter usually have lower explosive power and shorter ranges, but principally tactical military targets.

[45] See (Nuti 2007; Savranskaya and Blanton 2007; Wittner 2009).

[46] Two circumstances deserve mention in this context. On a general footing, the treaty imposed only the removal of intermediate-range weapons, without any obligation for dismantling or keeping track of them: as a consequence, counting how many tactical warheads still exist is one of the main problems presented by today's nuclear arsenals (see below). A relevant historical aspect is that recently declassified Soviet documents show that in the December 1988 New York meet-

In the meantime, around the mid-1980s, world nuclear stockpiles reached their maximum level, with a total of around 70,000 warheads, most of them tactical (the Soviet arsenal peaking at around 45,000, while the American one had been decreasing gradually since the mid-1960s—but its strategic arsenal peaking around the mid-1980s, too), see Figure 27.1 below.[47]

Figure 27.1: Quantitative consistency of strategic and non-strategic American and Soviet/Russian arsenals of nuclear warheads, 1945–2010. (Sourced at www.fas.org/ blog/ ssp/ 2009/04/ usrusnukes.php). This figure comprises active warheads, including spare warheads, but excludes those which are inactive, but still intact, and awaiting dismantling (in 1996 2,542 for US, 12,278 for Russia). The counting of non-strategic warheads is subject to major uncertainties, as is explained in the text.

27.8 What Changed after the Collapse of the Soviet Union and the End of the Cold War?

Deep changes occurred in the development and diffusion of nuclear technology after the end of the Cold War, although smaller than initially expected.

27.8.1 Early Hopes for Nuclear Disarmament ...

In fact, the collapse of the Soviet Union apparently made the deterrence role of nuclear armaments obsolete and opened up great hopes for their gradual elimi-

ing between Presidents Gorbachev and Reagan, the former was ready to proceed in the short term with the total elimination of nuclear armaments (Savranskaya and Blanton 2008); but the American president-elect participating in the meeting, George H.W. Bush, asked for more time to examine the problem, so this opportunity was lost.

[47] A table with the annual quantitative development of the American, Soviet/Russian, French, British and Chinese arsenals is given by: nrdc.org/nuclear/nudb/datab19.asp.

nation. This perspective seemed to be confirmed by several events, in spite of conflicting factors, until the second half of the 1990s. “Reduction” treaties of strategic stockpiles were established (Strategic Arms Reduction Treaty (START): START-I, 1991; START-II, 1993) instead of the “limitation” treaties (SALT) of the Cold War decades. A Comprehensive Test Ban Treaty (CTBT) was at last established in 1996 (although the main nuclear powers implemented powerful methods for the simulation of nuclear tests, see below).

In 1996 the International Court of Justice established that any threat or use of nuclear weapons would be generally illegal, allowing for the possible but uncertain exception under current international law of a circumstance in which the very existence of a state is at stake. But even then, for such use to be legal it would have to meet the standards of international humanitarian law; in other words, it would have to discriminate between soldiers and civilians, be proportionate, and not cause unnecessary suffering.

The 1995 Revision Conference of the NPT decided on the unlimited extension of the treaty, although the decision was taken at the end of inconclusive discussions, with the impossibility of assuming further binding conditions. The following 2000 Revision Conference resolved, for the first time, thirteen concrete, binding steps toward nuclear disarmament (Simpson 2001). A progressive reduction of the American and Russian strategic stockpiles began (see Figure 25.1).

27.8.2 …and Subsequent Disappointments

But this positive trend was subverted toward the end of the century. The Indian and Pakistani nuclear tests (1998) were a bitter (although widely foreseeable) surprise. In 1999 the US Congress rejected the ratification of the CTBT, which as a consequence never entered into force. The US withdrew from the ABM treaty,[48] and subsequently from START-II. The SORT (Strategic Offensive Reductions Treaty), or Moscow treaty, established by presidents Bush and Putin in 2002, cannot be considered a substantial improvement: even though it does impose the reduction of deployed strategic warheads to 1700–2200 each for 2012, it imposes no prescription for how to count them, nor for dismantling them (as did START-II), so that many more intact warheads will survive for a long time to come (see below).

Obviously, 9/11 caused a sharp increase in international tensions. The thirteen practical points agreed on at the 2000 Revision Conference were systematically ignored by the nuclear powers. The pace of removal (let alone elimination) of nuclear warheads and armaments was slowing down. Besides improving the

[48] This was a fundamental treaty (Anti-Ballistic Missile) for the balance of nuclear forces, limiting to two the number of missile defense systems that each block could deploy in order to prevent strategic superiority.

simulation methods for nuclear tests, all the nuclear powers undertook systematic programs of sub-critical tests.[49]

27.8.3 New Doctrines and Roles for Nuclear Armaments (under the George W. Bush Administration)

The main novelty—developed chiefly under the Bush Jr. Administration, and after 9/11—was probably the radical change in the military conception of the role, and possible *use*, of nuclear weapons, which in a few years turned them from obsolete relics into key components of the military systems. Actually, the growth of the Cold War stockpiles had been "justified" by their role of *deterrence*, since their mere existence and consistency would seem to prevent their use. But during the last ten years this strategy has been radically revised: the 2002 *Nuclear Posture Review*, especially, deprived nuclear armaments of a distinctive character, and placed them on the same footing as the other components of the military system. At present, nuclear armaments are therefore increasingly conceived to be materially usable in warfare, even on the battlefield, and in a pre-emptive attack. As such, they seem to have acquired an irreplaceable role, while the (real or supposed) problems of nuclear proliferation have achieved unprecedented relevance.

27.8.4 New Threats and Proliferation Dangers: Diffusion of Nuclear Technologies and Materials

These changes have brought about deep consequences for the transfer and diffusion of nuclear technology, in all their aspects. The environment has changed radically from the days of "Atoms for Peace." Apart from political or strategic considerations, the dangers of nuclear proliferation seem to be selectively and unscrupulously used either as a bait or a harsh complaint (in the latter case coupled with threats or hostile actions), whichever seems more expedient. I already cited the case of Brazil for the process of uranium enrichment. As far as proliferation is concerned, the case of North Korea is emblematic:[50] the 9 October 2006 nuclear test, explicitly justified by the "hostile politics of the US," suddenly sprang five years of unproductive *Six Party Talks*, and led to an agreement (although the negotiations have been subsequently complicated for other aspects). The message is clear: if you feel threatened, go nuclear! A "bivalent potential" adds to the dual-use property of nuclear technology: on the one hand, an instrument of threat or coercion by the main powers; on the other, for those who are—or feel—threatened, the ultimate deterrence.

[49] A complex class of tests in which no stable chain reaction is triggered. Complete nuclear tests no longer seem so indispensable, neither for verifying the operational status of the stockpiles, nor for designing or improving bombs (Garwin 1995), as compared with partial tests in which specific parts of the weapon are tested (von Hippel 1996; Drell et al. 1997; Younger 2000).

[50] In 2003 North Korea withdrew from the TNP, with the due three months' notice, reprocessed exhausted nuclear fuel, extracted plutonium, and three years later exploded its first nuclear bomb. See, for example, (Wit et al. 2004; Hecker and Liou 2007).

India's 1974 nuclear test demonstrated that the transfer of nuclear technology for non-peaceful goals is a reality. The sensitive aspects of nuclear technology and materials exchanges then led in 1978 to the publication of *Guidelines*, and the establishment of the *Nuclear Suppliers Group*: every exporting country must verify that the receiving country subjects the imported technologies to the system of safeguards. The system has been the target of criticism, from non-state actors as well.[51] On 28 April 2004, the Security Council of the UN adopted *Resolution 1540*, asking states to adopt more stringent internal laws and control measures, in order to prevent non-state actors from acquiring nuclear, chemical and biological technologies, establishing a *1540 Committee* to this end.

Nevertheless, the recent controversial *Civil Nuclear Cooperation Agreement* between the United States and India is a new cornerstone in nuclear technology transfer, legitimating—after three decades of ban on the sale of nuclear technology and material to India—the transfer of nuclear technology outside the framework of the NPT, toward a country which has signed neither this treaty nor the CTBT, and has ongoing programs to enlarge its stockpile. Although the agreement specifies that these transfers are limited to peaceful technology—through which India succeeded in developing its nuclear weapons nonetheless—it poses a new challenge to the *Nuclear Suppliers Group*.[52] The only possible conclusion is that from now on, the United States will set itself up as the utmost judge of which states mean to proliferate, and which not, thus imposing a supreme condition on the diffusion of nuclear technology. Currently it seems increasingly difficult to distinguish clearly between potentially proliferating and solely peaceful technologies, or to exert any real control over them. All the more so, if one takes into account the new or related techniques outlined above.

27.9 Present Problems, Perspectives, Dangers … and Hopes

The framework that is outlined briefly above holds serious challenges for the future. The new strategic context is pushing even more toward the further development of

[51] Up to 2002 the IAEA had listed 181 confirmed accidents concerning illegal trafficking in nuclear materials, including materials usable for bombs, eighteen of which concerned High Enriched Uranium (HEU) or plutonium (more than half during 1993–1995 and the remainder during 1999–2002) (IAEA 2002); see also, *Information on Nuclear Smuggling Incidents*: atomicarchive.com/Almanac/Smuggling.shtml; and the impressive sequence documented by the US Congress, 1996 Congressional Hearings Intelligence and Security, *Chronology of Nuclear Smuggling Incidents*: www.fas.org/irp/congress/1996_hr/s960320c.htm.

[52] The agreement met with strong resistance, even in India. Resistance was also manifested by several countries inside the *Nuclear Suppliers Group* (Ireland, Norway, New Zealand, the Netherlands, Austria, Switzerland), and was not overcome until September 2008 in the face of strong pressure from Washington and Paris. Authoritative experts claim that the agreement does not forbid the sale of potentially military technologies and materials, let alone the supply of uranium, implicitly permitting the use of India's limited stocks (it should suffice to consider that the IAEA will be allowed to inspect only civilian plants in India, not the military ones). See (Ahlström 2006, app.13B); the agreement is discussed in detail in (Kyle 2008).

connected or collateral fields, which threaten to shape a new arms race of unprecedented dimension and complexity. I will summarize the main aspects below.[53]

27.9.1 Nuclear Stockpiles, Reduction Treaty, Strategies: What Are the Perspectives for Eliminating Nuclear Armaments?

In April 2009 President Barack Obama promised substantial reductions of nuclear stockpiles, reviving the future perspective of their elimination, but the year of negotiations needed for the agreement with Russia on the new START treaty, and the formulation of the new *Nuclear Posture Review*,[54] bear witness to the deep difficulties and hurdles along this path. In fact, on a practical level, these achievements—although they have reopened direct talks between Washington and Moscow—amount to little, if any, progress. While the danger of ultimate recourse to nuclear weapons, although reduced, is not absolutely excluded (thanks to countries' non-compliance with NPT obligations: according to the unique opinion of the US, Iran is indictable but not Israel or India), stockpile reductions will be small: a ceiling of 1,550 warheads each in 2017, *vs.* the limit of 1,700–2,200 imposed by SORT (see above) by the year 2012. Actually, the total number of nuclear warheads still existing worldwide—in addition to those actively deployed (almost 5,000 strategic and nearly 2,500 tactical by the US and Russia, and almost 1,000 more by the other nuclear powers)—must include spares (a hedge that could be reloaded at short notice), and retired warheads awaiting dismantling, for a total exceeding 20,000[55] (to which thousands of plutonium pits and Canned Assemblies (secondaries) in storage should be added).

One more complex aspect concerns the relevance assumed by (or attributed to) non-state actors, and the (exaggerated or not) problem of terrorism, against which a role by nuclear weapons can scarcely be conceived.[56] Even so, the concrete danger of triggering a nuclear war by mistake has existed ever since the nuclear era began—and was avoided only by chance in several instances.[57] The danger of an all-out nuclear war is always with us, but even a local war could have terrible consequences on humankind, as for instance between India and Pakistan (Robock et al. 2008; Robock and Toon 2010).

But the problem is not limited to the reduction of warheads. The most serious danger is the unprecedented leap in the military system represented by the development of missile defence systems and arms deployed in space: even smaller nuclear arsenals could be suitable to increase the efficiency of such systems. The

[53] A comprehensive analysis of the problems concerning nuclear armaments is presented in (Baracca 2008, 2011).

[54] See (Department of Defense 2010a,b).

[55] Updated information can be found on-line in the "Nuclear Notebook" in the *Bulletin of the Atomic Scientists*, and in the SIPRI Yearbook (SIPRI Yearbook 2010); additional reports are published on the FAS Strategic Security Blog. For a general assessment, obviously limited to the Bush era, see (Cirincione et al. 2005).

[56] See (Ferguson et al. 2005; Allison 2004; UCS 2008; Walker 2010).

[57] See (Goldwater and Hart 1980; Arkin 1984; Sagan 1993; Phillips 2008; Hoffman 2009, 6–11).

ultimate condition for nuclear disarmament is reaching political consensus that it can be phased, transparent, verifiable, irreversible, and subject to strict and effective international control. As the Weapons of Mass Destruction Commission concluded authoritatively in 2006:

> So long as any state has such weapons—especially nuclear arms—others will want them. So long as any such weapons remain in any state's arsenal, there is a high risk that they will one day be used, by design or accident. Any such use would be catastrophic.
> (Weapons of Mass Destruction Commission 2006)

Concrete partial steps of utmost importance could consist in the enlargement of the Nuclear Weapon Free Zones,[58] above all freeing the Near East (even better, the entire Mediterranean basin, with neighboring zones) from nuclear armaments (Baracca 2006).

27.9.2 Programs for Improving Nuclear Armaments

Probably the most striking contradiction is the constant progress, by all nuclear powers, of extremely expensive programs for the improvement of nuclear warheads, above all, the continued development of all the other systems and complements of nuclear armaments (launchers, submarines, bombers, and so on).[59] It is no surprise that the whole military-industrial complex would appear to be the main obstacle on the path to eliminating nuclear armaments.

Research in new and related fields is taking on increasing relevance for novel developments and military applications. The most powerful computers are being built to improve the simulation of nuclear tests.[60] Another case is presented by developments in laser technology, which have given rise to at least two major sensitive military developments. On the one hand, the outstanding advances in super-lasers have made more concrete the possibility of simulating nuclear explosions in huge inertial confinement facilities as a means of designing new warheads, potentially accessible to even intermediate-level countries. In March 2009 the world's largest

[58] The Nuclear Free Zones already established cover Latin America and the Caribbean, South Pacific, Southeast Asia and Africa. See, for example, "Nuclear-Weapon-Free Zones (NWFZ) At a Glance," http://www.armscontrol.org/factsheets/nwfz.

[59] One concrete example should suffice concerning probably the most futile of the nuclear stockpiles (if any can be considered useful). Recently announced plans to replace the UK's Trident nuclear weapons system have been estimated to cost about £15–20 billion at 2006/2007 prices, not including running costs (Ministry of Defence 2006). The new coalition British Government is critically revising this choice. The Obama administration is seeking more than $5 billion in additional funding over five years to sustain the US nuclear complex and deterrent. The overall cost of the Stewardship Program for nuclear weapons in the US greatly exceeds the average budget for nuclear weapons during the Cold War.

[60] The most powerful to date is *Road Runner*, with 1-petaflop capacity (10^{15} operations per second), developed at Los Alamos National Laboratory. But France is building a 60-teraflop computer.

and highest-energy laser, the *National Ignition Facility*, was certified for operation in the US,[61] equipped with 192 laser beams for the nuclear fusion of a deuterium-tritium micro *pellet* (a true miniature pure-fusion explosion). France is competing with its ongoing *Mégajoule* project, with 240 lasers; other projects are under development in several other countries. The negative aspect is that progress in using such laser techniques for isotope separation seems to promise a method of uranium enrichment[62] that may be cheaper and more difficult to detect by means of inspections (Boureston and Ferguson 2005).

Some concern is also raised by the American *Stockpile 'Stewardship' Program* devised by the "Jason Division," officially for the maintenance of existing stockpiles (Drell et al. 1999), but denounced as overdimensioned and costly, and bearing the potential for designing new warheads (Kidder 1997; Lichterman and Cabasso 2000).

27.9.3 Problems with Fissile Materials and a Fissile Material Cutoff Treaty

Fissile materials, and the dangers of their military use, present at least three kinds of problems, however deeply interwoven: suspension of their production, regulation of their commerce, and controls on theft and illegal exchange. Diffusion models had to take into account both the need for openness essential to scientific innovation and commercial exploitation, on the one hand, and the need for secrecy imposed by the military implications of this technology, on the other. Clandestine markets, and the sensitive aspect of commerce in a dual-use technology have instead yielded "undesired" consequences like the Iraqi nuclear program, in which several Western countries possessing nuclear technology were involved.

Huge deposits of plutonium and highly enriched uranium (HEU) have been accumulated in the world, almost 1,800 tons each[63] (approximately 10% of plutonium has a military origin, as compared with 90% of HEU), as well as other fissile isotopes of military interest.[64] This poses unprecedented and increasing problems for the control of these deposits, increasing the dangers of illicit traffic and of nuclear arms proliferation. Nowadays it is generally believed that the construction of a nuclear weapon is relatively easy for a country with standard technical means: the main problem is probably procuring the nuclear material (plutonium or HEU). North Korea, as is recalled, is probably the most significant example: having nuclear reactors, it has obtained plutonium by reprocessing spent

[61]See the official site: https://lasers.llnl.gov/. For Mégajoule see, for example, (Allemand 2003).
[62]For general information on uranium enrichment see, for example, "Uranium Enrichment": nrc.gov/materials/fuel-cycle-fac/ur-enrichment.html; "Uranium Enrichment Techniques" globalsecurity.org/wmd/intro/u-enrichment.htm.
[63]In order to manufacture an "implosion" warhead designed sufficiently well, 4 kg of plutonium are potentially enough (the dimension of a beer can), or a triple quantity of HEU; a simpler warhead with the "gun" mechanism can be made with only HEU, not plutonium, and needs around 50 kg (Bunn et al. 2002).
[64]See (Albright et al. 1997; Albright and Kramer 2004, 2005; Albright 2005).

fuel. Most plutonium and HEU in military stores is inside warheads, in dismantled warheads or in stocks and naval nuclear reactors (which use highly enriched uranium), but military stores also contain huge quantities of surplus fissile material: almost 700 tons of HEU, and 100 tons of plutonium (not all from warheads) have been declared, which would be enough for 30,000 warheads. Moreover, for many countries like Israel, India and Pakistan, the estimates of these materials are extremely speculative, since they have not been submitted to IAEA inspections. In addition, there is a greatly underestimated problem of *latent*, or *stand-by* proliferation by some countries like Japan, which hold open the nuclear option as virtual nuclear weapons states, having both the technology and nuclear materials (huge plutonium stocks from reprocessed fuel) to develop nuclear arsenals in a very short time (Nuclear Control Institute 2002; Barnaby and Burnie 2005). Moreover, the IAEA estimates that more than thirty countries have sufficient fissile material, and technical skill, to produce nuclear weapons (Kothari and Mian 2001; Drell and Goodby 2003).

One of the most sensitive problems at present is the negotiation of a *Fissile Material Cutoff Treaty* (FMCT), putting an end to the production of fissile material, but even after decades no agreement has been reached, although the main powers have in fact stopped such production.[65] Several countries rightly maintain that for a FMCT to be credible it must impose on nuclear states, at least for the civilian nuclear sectors, the same verification procedures that the IAEA applies to non-nuclear states.

Concerns are raised by the at least one hundred research reactors around the world supplied with uranium enriched to levels of more than 20%, which is considered of potential military interest (Kuperman 2006; NTI 2007a,b): the case of the Tehran Research Reactor and enriched uranium has taken on great topicality in recent months.

The final step in fissile material control should consist in making such materials unusable for warheads, but the problem is far from solved. HEU can be diluted, but only to a limited extent, and some must be stored in waste depositories. As for civilian plutonium,[66] the main share is still contained inside spent nuclear fuel; another part comes from reprocessing, or is declared surplus military material. The partial use of plutonium in mixed fuel (MOX) in light-water power reactors can be hardly be expected to solve the problem, and may raise other inconveniences (Lyman 2001), unless the prospects of fourth-generation nuclear reactors should come true (see below).

27.9.4 Resumption of Civilian Nuclear Programs?

One more contradiction worth underlining is the increasing pressure all over the world for the resumption of large-scale civilian nuclear programs. As for nuclear

[65] A complete assessment is given in (IPFM 2008a). See also the synthesis (IPFM 2008b).
[66] See, for example, (Barnaby 2005).

armaments, these new programs rely on justifications quite different from those of the "Atoms for Peace" epoch. At present the main ones are the oil shortage and need to limit emissions of CO_2 into the atmosphere. Apart from the increasing proliferation of dangers and waste problems, critics object that—if one takes into account the whole nuclear cycle, from uranium mining to the management of radioactive waste, and plant and mine decommissioning—several phases emit CO_2: considering that the richest mines will be exhausted within a few decades, both the CO_2 and the energy balances are expected to become strongly negative (Storm Van Leeuwen 2008). Responding to these concerns is clearly crucial in order to evaluate the perspectives and sustainability of nuclear technology. Moreover, the possible development of nuclear production of electric power has no implication on oil dependence.

My personal opinion, which I cannot elaborate here, is that none of the (old and new) justifications for nuclear technology is unbiased, nor conclusive (Gronlund et al. 2007; Schneider et al. 2009). The nuclear production of electricity, after its boost during the 1980s, in fact gradually peaked around 2006 and is now declining: such a decline is expected to increase in the future since, prior to the few dozen new reactors under construction coming on line, many more will be closed over the next decades due to age limits. I maintain that civilian nuclear technology would not be sustainable by itself, and (directly or indirectly) bears heavily on military technology. The tight interdependency between the two sectors remains one of the most important aspects to be analyzed for a general appraisal of nuclear technology and its diffusion. Once again, the belief that a firewall can be drawn between nuclear energy and nuclear weapons is a general challenge to a new nuclear policy. No such firewall is possible, and nuclear reactors, for power or research, have fuelled the nuclear programs of Israel, India, Pakistan, North Korea, as well as presenting future proliferation risks. The designation of peaceful nuclear power as an "inalienable right" in the NPT is a contradiction that must be addressed if nuclear proliferation is to be controlled.

A few words must be dedicated to the so-called "fourth-generation" power reactors. Their putative characteristics are supposed to solve (or highly simplify) the bottlenecks of nuclear power, i.e. the problems of shortages of nuclear fuel, safety, and the amount and dangers of nuclear waste, making nuclear power "sustainable." Some reservations are in order. In the first place, these technologies are still being developed, and are not expected to become commercially viable before 2030–2040.[67] I would add that it seems at least surprising that a technology which promises such advantages requires so long to be completed: since several of the prototypes under development are fast-neutron, metal-moderated reactors, one should probably call to mind the possible surprises such a complex technology might hold in store, as did the French fast-reactor program after three decades of development (although it certainly was successful for the French military program) (Cochran et al. 2010).

[67] A general assessment in their favour is (European Commission 2007).

Nuclear energy suffers from some basic drawbacks due to intrinsic physical limitations. The (first law) efficiency[68] of a nuclear plant is quite rigidly restricted to around 30% for the intrinsic limitations of uranium fuel and the uranium fuel cycle (although the combined gas-vapor cycle has been improved substantially and now approaches 60%), while the second law thermodynamic efficiency is even smaller, due to the extraordinarily high thermodynamic quality of nuclear energy (which corresponds to millions of degrees) compared with the demanded temperatures of hundreds of degrees. Thermal, low-temperature, use of the energy released from nuclei (corresponding to millions of degrees) can be considered a true "thermodynamic slaughter"!

27.9.5 Radioactive Pollution and the Health Dangers of Ionizing Radiation

Last but not least, the general problems of the radioactive pollution of the atmosphere during the nuclear era, along with the assessment of the health dangers of ionizing radiation, are in my opinion largely underestimated. This problem is extremely complex, and scientifically controversial. Although sixty-five years have passed since Hiroshima and Nagasaki, the main source of information remains the periodic revision of the data from those events. The assessment of the dangers of radiation, and of the "allowed" doses, is officially determined by the ICRP (International Commission on Radiation Protection), but its prescriptions and the very bases of its analyses are deeply criticized by independent scientists.[69] The problem of low radiation doses is particularly controversial. Moreover, a serious problem of radioactive pollution in the planet's atmosphere has been reported, originating from nuclear tests in the atmosphere, subsequently from the widespread applications of nuclear energy and technology, and more recently from the military use of depleted uranium.[70] There is also increasing evidence of the health effects of

[68] "First law efficiency" is the ratio of the useful (electric) energy output to the total energy developed, as heat, by the chain reaction in the core. "Second law efficiency" is a completely different parameter, which takes into account the respective *thermodynamic qualities* of the input and output energies, related to their temperatures. See, for example, (Gilliland 1978; Wikipedia 2010). Considered as a thermodynamic engine, as it actually is, a nuclear reactor is an *external* combustion engine and could never become an *internal* combustion engine.

[69] It is interesting to recall, however, that the scientific awareness of the damage to health and the environment from ionizing radiations and nuclear tests goes back to wartime research, but was hidden from public opinion. In 1943 the scientists Conant, Compton and Urey sent the director of the Manhattan Project, General Groves, a memorandum, held secret at that time, on the "Use of radioactive materials as military devices": mindfully.org/Nucs/Groves-Memo-Manhattan30oct43a.htm. This document recommended their use in the battlefield, specifying that the thin radioactive particles would penetrate every gasmask. For nuclear tests, too, it is remarkable that the Soviet scientist Sakharov estimated back in 1958 that, for each megaton of nuclear explosive power in the atmosphere, even at low doses, almost 10,000 persons would suffer from cancers, genetic mutations and other illnesses (Sakharov 1958).

[70] See, for example, (Sternglass 1981, 2009; Bertell 1999; Busby et al. 2003; Mangano et al. 2003; Moret 2003; Baverstock 2005; Naruke et al. 2009), suggesting the presence of a late effect of

living in proximity to nuclear plants and of accidents at such facilities.[71] In particular, this group of scientists shares the opinion that the consequences of the 1986 Chernobyl disaster have been covered up.[72] As one of the main inconveniences for seriously tackling this kind of problem, the balance between the WHO and the IAEA, is strongly criticized for depriving the former of autonomy regarding issues related to radioactivity (Tickell 2009).

27.10 Conclusions

The entire set of problems I examined synthetically poses very serious challenges for civil society, for international relations and for the scientific community, in spite of the controversial or debated aspects.

From a general point of view, I would remark that, among all technological advances of humankind, nuclear technology is probably the most artificial, "unnatural," one, since it has activated physical processes that do not occur, not even in small fractions, in the environment in which we live and act (while they are basic processes in the interior of stars, at millions of degrees), therefore yielding artificial products which cannot be recognized and handled by the natural processes which act at the extremely lower temperatures prevailing on our planet. This is a fundamental difference with respect to all chemical processes, which depend only on the external electrons on atoms, but by no means on their nuclei. This is the fundamental root of the peculiarities of nuclear armaments, their terrible power, consequences and unmanageability. This is also the reason why nuclear waste cannot be eliminated. It is deeply striking to me that nobody wonders about the fact that nuclear waste has to be protected and guarded for periods of 300,000 years, a recommendation which goes beyond any reasonable scientific criterion and historical record: can anybody foresee or guarantee the conditions on the planet thousands of years from now? I think that it is scarcely possible to manage any problems that are *created* by nuclear processes by trying to *limit their dramatic consequences*, or stop them once and for all, let alone to actually *solve* them.

As far as the scientific approaches are concerned, it seems worth remarking on the existence of problems that can seriously bias or distort scientific and technical research. The British Association of Scientists for Social Responsibility has produced a series of studies on the dangers that military influence is wreaking on universities.[73] Although devoted mainly to British universities, the conclusions of the reports have more general validity. The military involvement in the R&D of universities supports a narrow weapons-based security agenda, marginalizing both a broader approach to security—which would give much greater priority to

A-bomb radiation, which may indicate a predisposition to cancer. For the problem of depleted uranium, see (Bertell 2006).

[71]See (Mangano 2000, 2004, 2009; Fairlie 2008).

[72]See (Busby and Yablokov 2006). The most recent and worst prognosis can be found in (Yablokov et al. 2009).

[73]See (Langley et al. 2005, 2007, 2008).

supporting conflict prevention by helping to address the roots of conflict—and underfunding in comparison to other R&D fields that aim to tackle poverty, climate change and ill health, and thus help to provide basic security for human populations. As an example, in 2004, governments in industrialized countries spent a total of $85 billion on military R&D, but only $50 billion on R&D for health and environmental protection, and less than $1 billion on R&D for renewable energy. The reports add that, despite the introduction of the Freedom of Information Act (FoIA), the ability to obtain detailed information on military involvement in R&D, especially within universities, remains so highly problematic that further reform is needed. I could add to these conclusions that such research does not address the other side of the coin, namely the large share of the scientific community which works directly in military laboratories, and the certainly much higher budget on which they rely.

Addressing these problems, and bringing their knowledge and consciousness to civil society, is in my opinion a crucial aspect in the perspective of eliminating the ominous dangers and the problems raised by the nuclear era. An encouraging aspect is the existence of a vibrant movement for peace and nuclear disarmament.

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Chapter 28
The Role of Open and Global Communication in Particle Physics

Hans Falk Hoffmann

> The Organization shall provide for collaboration among European States in nuclear research of a pure scientific and fundamental character, and in research essentially related thereto. The Organization shall have no concern with work for military requirements and the results of its experimental and theoretical work shall be published or otherwise made generally available.[1]

28.1 Introduction

For over six decades the scientists and engineers of particle physics together with their funding agencies have undertaken the global management of their science, with visibly good results. An open, unrestricted, transparent and fertile environment is provided for all sustainably funded and interested scientists by sharing expenditures globally. All findings of the science, both scientific and technical, are available to anyone who is interested, anywhere in the world. The participating scientists or engineers have and exercise the possibility to speak their minds and to engage in the decision-making-process of this critically communicating, all-hands-involved and democratic science.

For around twenty years, efforts have been in progress to make such newly arising knowledge generally available online. Before the availability of electronic libraries, publications were generally distributed as preprints, advance copies of papers submitted to refereed journals. Today, “open access” or “OA publishing” on the Internet has been adopted almost universally in this science. A “public domain” or a “commons” of sharing and owning knowledge, resources, relationships of trust, collaboration and of efforts is an integral part of this science. These commons are accessible to all other sciences, at least via OA publishing.

This chapter will introduce the science and its governance, explain its open, democratic, self-organizing and collaborative methods, its sharing of insights, its modes of global “agenda setting,” its detailed processes of decision-making and

[1] From the “Convention for the Establishment of the European Organisation for Nuclear Research, CERN,” ratified in 1954 by its member states, published, for example, in Germany in (BGBL 1954).

quality control, and undertake to show the added value and also the inconveniences of this way of doing science. It will not attempt to demonstrate the difficult, tortuous and sometimes chaotic paths and scientific reflections of individuals or communities that are necessary to move from one particular scientific model to the next.[2] It is not concerned with the particular scientific or technological choices that are made, or why, but it will point out the ever more complex instruments and, in particular, the e-infrastructure required to allow all participants to be fully aware of all forms of knowledge relevant to the progress of the science. The evolution of the CERN LHC project, its accelerator and its experiments, occupying more than half of the global community of particle physicists, will be used to demonstrate the principle point of the paper:

> All knowledge, skills and know-how within this science are common goods, elaborated in a continuous and structured dialogue between equal partners, available without restriction to all participating scientists, supported by a powerful electronic infrastructure to make them available to all participants immediately and everywhere. The community values every scientist's opinion and encourages intense communication and exchanges of opinions. Hierarchies are rather flat.[3]

Particle physics and other cosmic sciences are rather unique examples of fundamental sciences since they are mostly free from external influences such as political, military or commercial requirements. They enjoy considerable public interest in their complex, innovative instruments and their fundamental subjects, which describe important aspects of the evolution of our universe. They also create interesting, unsolicited and sometimes spectacular spin-offs. Obvious examples are the creation at CERN of the World Wide Web in 1989/90 and its positioning in the public domain[4] or the use of particle physics instruments for radiotherapy and medical or technical diagnostics. Most importantly, every year particle physics attracts, educates and releases into industry or academia thousands of young scientists and engineers.

In contrast, and not in "cosmic" sciences, the use and availability of knowledge changes drastically when military superiority or industrial profits from scientific

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[2]See, for example, (Renn 2006).

[3]This is the author's view of the workings of a collaboration in particle physics from decades of working within such collaborations. One ingredient is the CERN convention (see footnote 1) and its requirement to make all findings generally available. The formal organization statements of the collaborations demonstrate another aspect as they represent the community's decisions of how they want to collaborate in practice. The ATLAS organization can be taken as typical example from the ATLAS technical proposal (LHC Experiments Committee 1994, chap. 10.5.1, 205). The ATLAS organization chapter describes the roles and responsibilities of every member and every institute of the collaboration as well as of all officers of the collaboration and their limited terms of office and regular election processes. The ultimate authority is the regular "all hands plenary meeting."

[4]Compare, for example, "The World Wide Web Consortium (W3C)": http://www.w3.org. A description of the Web's history can be found in (Gillies and Cailliau 2000).

applications promise exclusive advantages. Free communication, the availability of data, information or results and information on potential applications is then severely channeled, restricted or suppressed. Equally, the advances of scientific efforts which are dominated by restricted availability of knowledge and by research agenda-setting following non-scientific interests make sciences appear to progress more slowly or in a biased fashion toward their general, high-level goals.

Following the example of complete openness that is typical for fundamental research, there is a growing tendency to establish similar openness in other fields, particularly in medicine and the life sciences,[5] claiming that publicly funded research should make its results generally available as a public good. Between the restrictive proprietary use and availability of knowledge generated by industries or for military purposes and the generally available knowledge, there is a wide area of application of knowledge and setting of research goals where the public good should be favored over private interests. Many voices challenge the present balance, which seems to be more on the side of private, even if multinational, or national security interests.

Thus, the use of knowledge and the unbiased setting of research agendas have become a prominent side issue of global governance. Here are some examples: The recent UN/ITU World Summit of the Information Society expressed in its declaration of principles its

> […] common desire and commitment to build a people-centered, inclusive and development-oriented Information Society, where everyone can create, access, utilize and share information and knowledge, enabling individuals, communities and peoples to achieve their full potential […]

The declaration further promotes a dedicated strategy of sharing scientific knowledge, technological skills and best practices in science education and applications as essential for the development of less developed countries.[6]

The European Research Council has begun to speak about the desirability of a fifth European freedom: the free circulation of knowledge and the conditions to make it happen.[7] This is in complement to the four established freedoms of the EU: the free circulation of goods, capital, services and persons.

Indeed, between the strictly proprietary, profit- or military-oriented endeavors and fundamental scientific goals, there is a large spectrum of global priority goals which would be better treated with global interests in mind and with all available knowledge at the disposal of all scientists concerned. Examples of such possible global goals are evident in the UN Millennium Development Goals, or

[5] For example, the public accessibility of research sponsored by the US National Institutes of Health: http://publicaccess.nih.gov.
[6] See (WSIS 2003), cf. also (Dosanjh and Wilkinson 2004).
[7] See (CORDIS 2007) or (ERA 2007).

more specifically concerning health in the "Global Burden of Disease" reports of WHO,[8] both of which are concerned with the majority of the world population.

Public research and education, health, poverty and hunger, climate and sustainable energy provision, biodiversity and sustainable environment are amongst the promising subjects for global knowledge based approaches. The global communication, sharing and governance practices and the commonly constructed and used infrastructures described here may provide "food for thought" for other sciences and their global self-governance. In particular, the role of intellectual property from publicly supported science should move from individual exploitation toward a more common availability.

28.2 Particle Physics: A Global Science

28.2.1 The Science

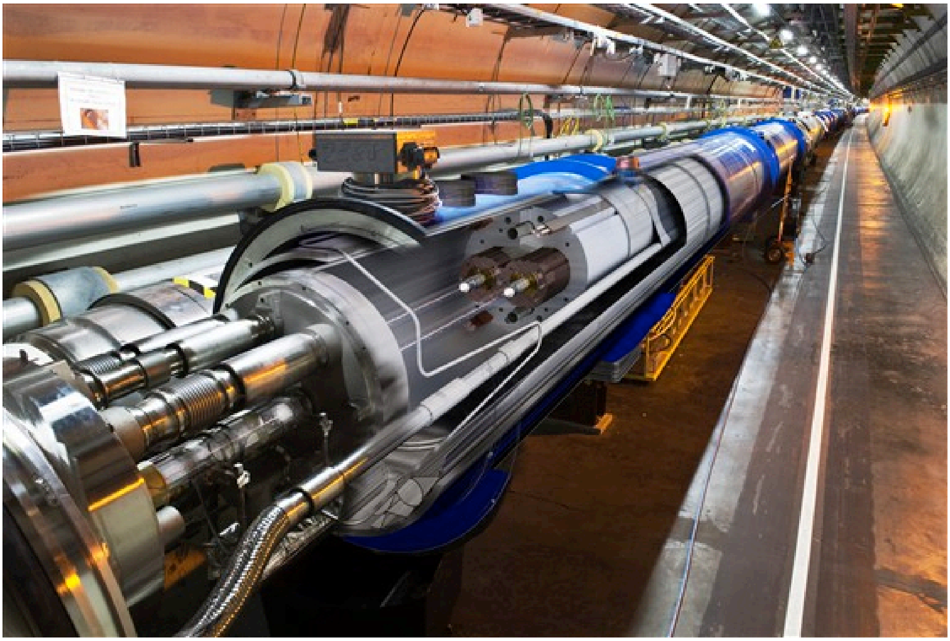

Figure 28.1: Superconducting Magnets of the LHC.
(CERN-AC-0911188 01 ©CERN)

[8]Compare, for example, the "UN Millennium Development Goals": http://www.un.org/millenniumgoals, and the WHO "The Global Burden of Disease": http://www.who.int/healthinfo/global_burden_disease/en.

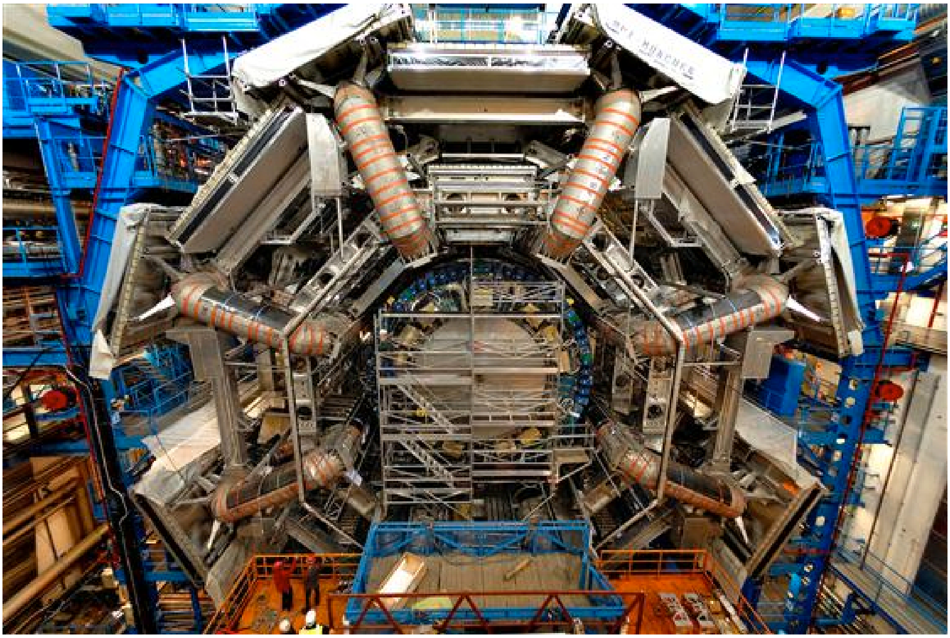

Figure 28.2: ATLAS experiment during assembly. (CERN-EX-0610006 ©CERN)

Thanks to fundamental research in physics, we know that all the matter we can see in the Universe is made up from a handful of elementary particles, and particle physics can tell us with good precision about the way these particles interact among themselves. However, we also know that what we see in the Universe accounts for only a few percent of what we know to be there. About the rest, named dark matter and dark energy, we know almost nothing.

That we occupy such a small fraction of our Universe is fascinating, and extending our knowledge here is in itself a good reason for pursuing this fundamental research. With the Large Hadron Collider project today in construction at CERN (compare Figures 28.1 and 28.2), we hope to undertake some further steps to find some missing details of the known 5% and clues as to what the remaining unknown 95% are, and how they relate to the familiar 5% that we inhabit and know.

The method of particle physics is to explore matter at very small distances or, equivalently, at very high temperatures or energies. To this end, using accelerators elementary stable particles such as protons or electrons are brought to collision at ever-higher energies. The available energy of the moving particles in the center of mass system of the collision partners is available through the "matter – energy – equivalence" to create new particles. International collaborations conceive and construct experiments to observe such collisions.

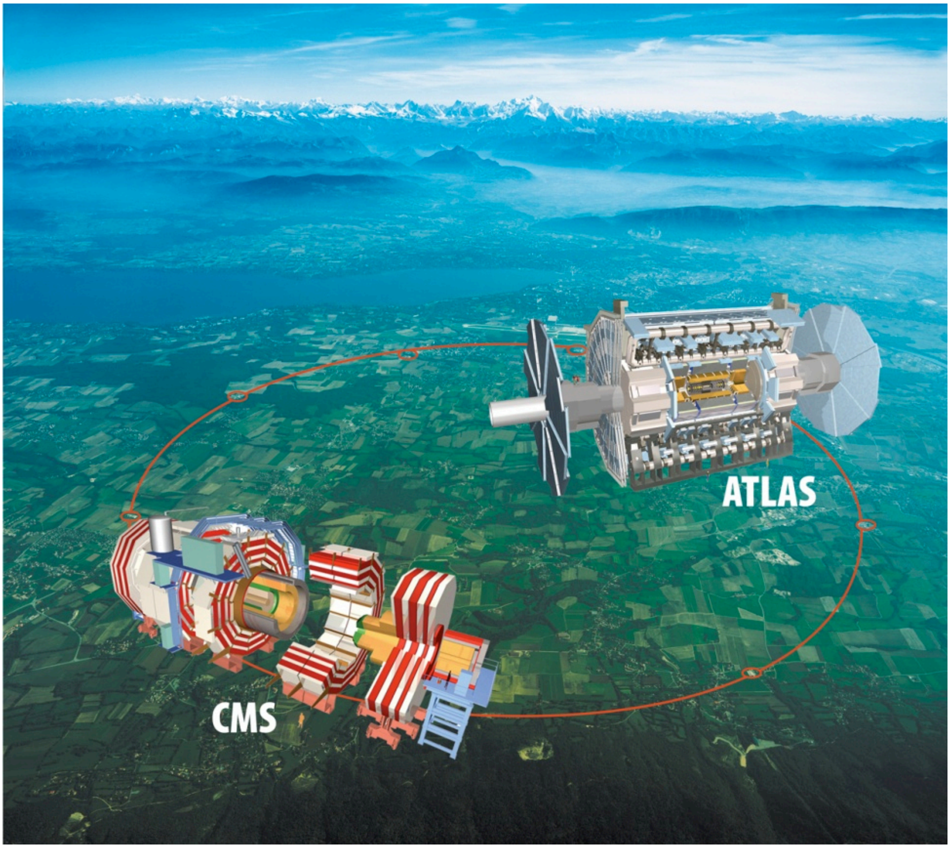

Figure 28.3: The 27km underground tunnel of the LHC accelerator (red circle) and cut-away drawings of CMS and ATLAS at the position of their underground collision areas. (CERN BUL-PHO-2009-064 3 ©CERN)

The LHC project[9] is a European and now global project consisting of a 27 km-circumference, superconducting accelerator for creating high-energy collisions with temperatures as high as the temperature of the universe a small fraction of a second after the big bang. Two "general-purpose" experiments, ATLAS[10] and CMS[11] are conceived to observe the behavior of such collisions as completely as

[9]Technical papers describing the LHC and its experiments can be found in the special edition of the electronic journal *JINST*, the Institute of Physics (IOP) electronic *Journal of Instrumentation*: http://www.iop.org/EJ/journal/-page=extra.lhc/jinst. A more popular description of the LHC accelerator and the corresponding experiments can be found in (Evans 2009).
[10]ATLAS homepage: http://atlas.web.cern.ch/Atlas/index.html.
[11]CMS homepage: http://cms.cern.ch.

possible (see Figure 28.3). Among the main subjects of interest derived from particle physics theories and past findings are Higgs-searches or alternative schemes for the spontaneous symmetry-breaking mechanism, searches for super symmetric particles, dark matter, effects from extra dimensions, new gauge bosons, leptoquarks, or quark and lepton compositeness indicating extensions to the Standard Model and new physics beyond it.

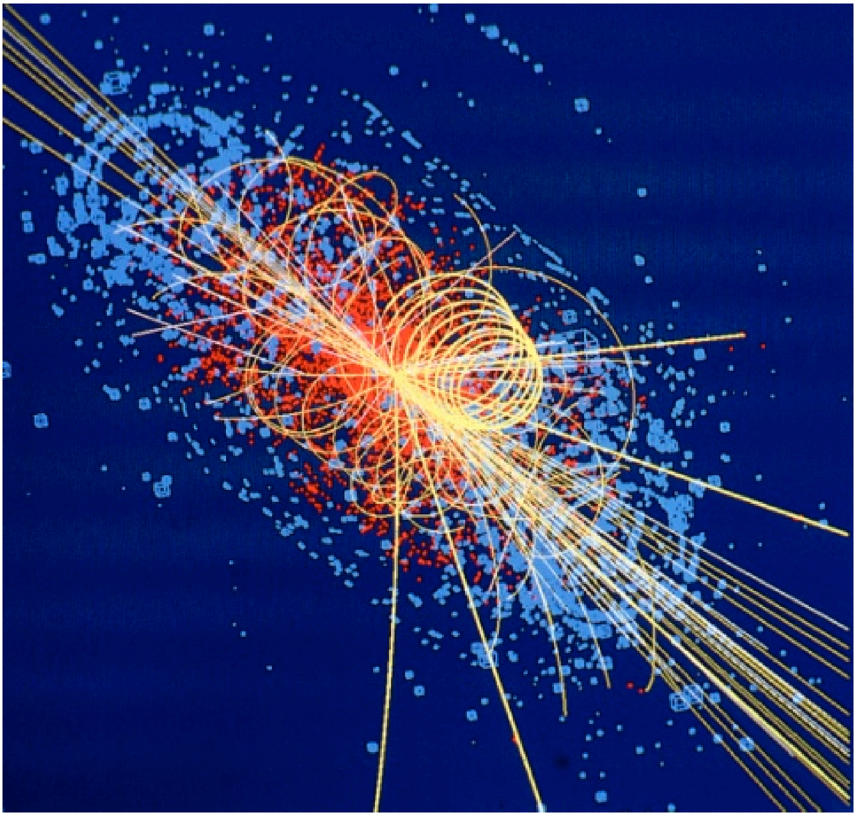

Figure 28.4: CMS simulation of a Higgs-boson decay to four muons. (CERN-EX-9710002 1 ©CERN)

There are two such experiments, made by independent and competing collaborations, which serve as an ultimate quality control to substantiate any findings of new physics. Even then, competition applies for discoveries only and there is exchange in technologies, accelerator-experiment interfaces and other matters. Two more experiments specialize on specific aspects of the collisions, LHCb[12] on the

[12]LHCb homepage: http://lhcb.web.cern.ch/lhcb.

differences of matter and antimatter states of the b-quark and ALICE[13] on heavy ion collisions. There are some smaller experiments.

Figure 28.4 shows an example of a simulated collision modeled for the CMS detector of the Large Hadron Collider LHC at CERN, producing a Higgs boson in a 14 TeV collision of two protons, entering along the diagonal and colliding in the center of the figure. The Higgs boson decays almost instantly into four muons, the rather straight yellow lines at larger angles. Collisions in the LHC occur at random and an event such as is shown in the simulation—event production and branching ratio into detectable decays—happens very rarely, at a level of 1 in ~10^{13} to 10^{14} of all collisions. For comparison, the straight tip in lotto is about 1 in 10^7, one to ten million times more frequent. Understanding such rare events requires studying and understanding all the physical processes that generate events in sufficient detail to be able to select the rare and interesting ones unambiguously.

The useful lifetime of LHC and its experiments is estimated at ten to twenty-five years depending on scientific output and potential upgrades. During such a time span, a phenomenal amount of data will have to be selected, stored and analyzed.[14] The scientific potential of LHC corresponds to the expectations of the majority of the global particle physics community, who have regarded the LHC as a priority scientific activity since the mid-1990s, after the demise of the even more ambitious Superconducting Super Collider, SSC project[15] in Texas, USA.

28.2.2 The Community

Particle physics today is spread over most developed and a number of less developed countries, with 15–20,000 scientists and engineers in universities, academies and particle physics institutes, about 600 different institutes in about 70 nations.

In the interest of doing competitive research, scientists in particle physics agree to invest a considerable portion of their available resources in large laboratories capable of providing the required accelerator infrastructures and of providing the community with almost free access to their facilities. A large part of the community aggregates into collaborations to construct and exploit the ever more complex experimental tools that are necessary for the science. Section 28.3 will attempt to explain how individual academic freedom within competent institutes—a prerequisite for successful, curiosity driven research—is preserved and cultivated in such a highly structured environment.

After World War II, eminent scientists, politicians and the UNESCO proposed to return to open, non-military fundamental nuclear science and suggested the construction of large laboratories that could provide accelerators and beam lines for university scientists. Indeed, the first laboratories were then founded: BNL (1947) on Long Island by the US; CERN (1954) in Geneva by twelve member states;

[13] ALICE homepage: http://aliceinfo.cern.ch.
[14] See section 28.4.
[15] See http://en.wikipedia.org/wiki/Superconducting_Super_Collider, and (Riordan 2000).

and JINR (1956) in Dubna by eleven member states. Today, other such major accelerator laboratories can be found in Europe: DESY[16] and GSI[17] (Germany); in the Americas: FNAL and SLAC (US)[18] and TRIUMF[19] (Canada); in Asia: KEK (Japan) and IHEP (China)[20]; and finally in the Russian Federation: IHEP[21].

The principal infrastructure items are the accelerators, beam lines and collision areas with their ancillary technical equipment for the accelerators and experimental equipment as well as in-house shops and engineering services.

In the past sixty years, the collision energies have grown by about four orders of magnitude based on many innovative changes of accelerator technologies used.[22] Similarly, the sensitivity, speed and selectivity of experimental set-ups have undergone even more drastic changes with the development of many novel particle physics detection devices[23] and their integration into multi-purpose devices.

In the 1950s to 1960s the large laboratories conceived, constructed and operated accelerators and experimental facilities such as bubble chambers whereas university teams mostly analyzed data. Today, CERN constructs the LHC with 15% external resources, people and funds. Indications are that a next world accelerator—if ever built—would be constructed in collaboration[24] with order of 50% external contributions, sharing resources and governance on a planetary level. In contrast, the worldwide community outside of the large laboratories already provides 80% of all resources required for the LHC experiments and CERN 20%, demonstrating the deliberate move of skills into the community at large in the past decades.

The funding of particle physics comes from many national sources, which guarantees some stability. The LHC and its experiments are constructed and operating and will be sustained throughout their useful scientific life. Funding agencies are well-disposed toward particle physics since promises of performance, cost and scientific achievement are usually kept. At present, there are enough resources to pursue minor development works for future accelerators and novel features in experiments.

Approximately two thirds of the global particle physics community are currently engaged in the LHC project at CERN.[25] CERN employs a staff of around 2400, of which more than 1000 are academics, mostly physicists and engineers, ~300 work in experimental and theoretical physics, ~150 in computing and ~600

[16]Desy: http://www.desy.de.
[17]GSI: http://www.gsi.de/portrait/index.html.
[18]FNAL: http://www.fnal.gov; Brookhaven National Laboratory: http://www.bnl.gov/world; Stanford Linear Accelerator Center:http://www.slac.stanford.edu.
[19]Triumf: http://www.triumf.info.
[20]KEK: http://www.kek.jp/intra-e; IHEP: http://www.ihep.ac.cn/english/index.htm.
[21]JINR: http://www.jinr.ru; IHEP: http://www.ihep.ru.
[22]See, for example, (van der Meer 1985).
[23]See, for example, (Charpak 1993).
[24]See (Heuer 2009). See also: International Linear Collider website: http://www.linearcollider.org.
[25]See CERN: http://public.web.cern.ch/public and (Hermann et al. 1987).

in accelerators and infrastructure. About 10,000 scientific users, physicists and engineers from about seventy countries (~5900 from the European member states, ~2800 from the observer countries[26] and 750 from forty other Nations) consider the LHC project and its scientific or technological goals as their principal research subject. Around 20%–30% of them are present at CERN at any time for periods ranging from one year to one day. More than 30% of these scientists are Master- or Ph.D. or postdoctoral students and consequently the whole population changes at a rate of about 20% per year.

Most of these scientists and engineers work in the four large collaborations, ALICE, ATLAS, CMS and LHCb. Their participating institutes define amongst themselves their rules of collaboration, the sharing of resources and governance. Most importantly, they set their own scientific goals and elaborate the corresponding experimental set-ups in competition with other groups.

Apart from these laboratories and collaborations, there are also collaborations that deliver important services to the community:

1. The Particle Data Group[27] is a collaboration of more than 150 scientists, which presently delivers an impressive data curation service for the community's awareness with a comprehensive and state-of-the-art summary of particle physics. For over fifty years, the PDG has been offering peer-review and summaries of all theoretical and experimental findings in particle physics.
2. Event generators—Monte Carlo programs simulating high-energy (LHC) collisions—based on current particle physics phenomenology and recent experimental results are at the interface between theory and experiment and allow the simulation of all that is presently known about a possible creation of new particle physics phenomena or particles, for example, the above-mentioned Higgs particle.[28]
3. The passage of particles through matter, for example, resulting from an event generator, can be described in great detail today in elaborate Monte Carlo simulation codes[29] after many decades of effort starting from electromagnetic showers in matter to include strongly interacting particles and numerous other fine details. Such programs allow the simulation of collisions with hundreds of particles within experimental set-ups consisting of millions of different components represented in their actual shape and material composition.
4. ROOT[30], an open source, "object oriented" software package for storing, mining and analyzing large amounts of data is developed in 'Bazaar-Style'

[26] Currently India, Israel, Japan, Russia, Turkey, and USA.
[27] See http://pdg.lbl.gov and their latest publication (Amsler et al. 2008).
[28] See, for example, (Corcella et al. 2002, 2005). There are many other event generators such as Phytia, Sherpa, and others.
[29] See, for example, GEANT4: http://geant4.cern.ch and FLUKA: http://www.fluka.org.
[30] This is a data storage, mining and analysis software package for physicists, authored by Rene Brun, Fons Rademakers and many others: http://root.cern.ch/drupal; for an introduction, see: http://root.cern.ch/download/doc/1Introduction.pdf.

(Raymond 2001) by a community of interested scientists. ROOT or ideas and parts of it are used in LHC experiments and other scientific efforts.

Many other "service" collaborations exist for developing and pursuing research and design (R&D) in accelerator and experimental technologies.

Theoretical physicists reside mostly in universities and academies, but all large laboratories have theoretical physics groups and offer a small number of prestigious positions. With their meeting facilities and the latest experimental findings, accelerator laboratories attract numerous topical meetings, offer fellowships and temporary visiting scientist positions to theoreticians in order to encourage their close interaction with the experimentalists. The theoreticians express in their theories the findings of the experiments in the context of what is known or what might be a new phenomenon. They give scientific input to the desirability of new accelerators and experiments and advise on the interpretation of results. They work on the next and more encompassing theories of particle physics and cosmology. Online publications, e-prints, using for example, *arXiv*,[31] and all other means of communication have made theoretical particle physicists around the world a closely interacting, but mostly unstructured and distributed community.

The most important feature of the whole community is that all knowledge, know-how and particular skills are shared freely and instantaneously, from engineering advances to the latest theoretical hypotheses. Institutes are basically free to choose with whom they collaborate as long as they meet the requirements of the collaboration they want to join.

28.2.3 Governance in Particle Physics: Interplay of 'Informal and Bottom-up' with 'Formal and Top-down'

Member state funding agencies govern the multinational accelerator-laboratories such as CERN (and JINR) by means of a council formed from scientists and government officers from all member states. The council is supported by a scientific policy committee of eminent scientists from the global community and a finance committee composed of financial officers from all member states. Countries contributing significantly to the LHC accelerator obtain observer status[32] and participate fully in all dealings concerning the LHC project.

For national accelerator laboratories, national structures replace 'council' functions. There is a large variety of funding and supervision schemes for universities, academies or other institutes working in particle physics.

Accelerator laboratories conceive and construct their accelerators as part of their own objectives and goals and within their own organizational and supervisory structures. New projects advance only after ample discussions with and positive feedback from the international user community. All new accelerator projects

[31] Open access e-prints: http://arxiv.org.

[32] See footnote 26.

are accompanied by peer review ‘machine’ committees with members from other accelerator laboratories or universities undertaking accelerator research.

Accelerator laboratories have formalized their relations with a number of committees, created ad hoc to achieve coordination at regional and world level with other such laboratories and the community:

1. The European Committee for Future Accelerators ECFA[33] was set up at the beginning of 1963 on the initiative of Professor Weisskopf, then Director-General of CERN, to provide community feedback to CERN, DESY and other laboratories in Europe and to coordinate their activities involving governments, institutes and scientists. Committee members are proposed by the community and nominated by the member state governments.
2. For over twenty years, a similar committee ACFA[34] has existed for Asian countries.
3. The International Committee for Future Accelerators ICFA[35] plays a role of early exchange and coordination of the particle physics laboratories and the community worldwide. It was founded as a regular meeting of the heads of the major laboratories in the late 1960s to early 1970s to avoid duplication of efforts in particle physics. There are regular annual meetings and global ICFA workshops summarizing the state-of-the-art of particle physics on a regular basis.

The ICFA, however, could not resolve the conflict over the competing projects SSC[36] and LHC. The CERN LHC project survived the competition as the less costly proposal backed by many nations; it eventually integrated the SSC user community.

Experimental collaborations aggregate outside of such governance. However, they face severe and high-level scientific and technical peer reviews throughout their existence. Such peer reviews report to the host laboratory’s management and supervisory councils and committees. Any institute may join provided it takes an agreed share of resources for construction, operation and maintenance, and exploitation of the experiments.

Throughout their lifetime, CERN experiments are supervised by “Resources Review Boards” who authorize the use of resources of experiments with participation beyond countries represented in the CERN Council. They also follow the progress of the performance goals. Their proceedings are reported to the Council by CERN management.

Today the ATLAS and CMS collaborations alone each have around 2500–3000 scientific or engineering collaborators who conceive, construct, operate, maintain and exploit their devices. The lifespan of such collaborations is about four decades:

[33] ECFA: European Committee for Future Accelerators, compare http://ecfa.web.cern.ch/ecfa/en/Welcome.html.
[34] ACFA: Asian Committee for Future Accelerators, compare http://www.kek.jp/acfa.
[35] ICFA: International Committee for Future Accelerators, compare http://www.fnal.gov/directorate/icfa.
[36] See footnote 15.

half for construction and half for exploitation, corresponding to several generations of scientists. The yearly budget of each of them for construction, exploitation, and human resources corresponds to the budget of a sizeable international laboratory. However, they are not legal entities in their own right and are represented by CERN. At the end of their exploitation, they cease to exist.

Each participating institute and its funding agency signs a memorandum of understanding (MoU) for the construction and exploitation of the corresponding experiment. The MoU defines the purpose of the collaboration, the participants, the deliverables of each institute, the overall schedule, the internal organization and responsibilities, the deliverables, the facilities and areas of the host organization made available for the experiment, the quality control and the supervising bodies of all funding agencies and the host laboratory. The MoU is not legally binding, but institutes and funding agencies recognize that "the success of the collaboration depends on all its members adhering to its provisions."[37] "Deliverables" are services or equipment attributed with a value in a convertible currency by the collaboration, with precise specifications and predetermined delivery schedules; they are executed under the entire responsibility and with the resources of the corresponding institute. Taking entire responsibility for parts of the experiment producing a deliverable reduces transfer of funds, ensures the use of local competences and mastering of the corresponding technologies by the institute concerned. The collaboration executes a rigorous quality control on all activities and parts, making use of external experts in the particular fields of technologies or sciences involved.

Experiments[38] organize themselves in a "bottom-up" manner guided by principles such as democracy, separation of policy-making and executive tasks, minimal formal organization and limited terms of office. The Collaboration Board, the representation of all participating institutes (about 170), is the policy-making and decision-making body of the collaboration. Every participating institute, CERN for example, has one vote. The Collaboration Board elects the spokesperson of the collaboration after nomination of candidates and in due consultation with the collaboration and with the host laboratory. The spokesperson is responsible to the Collaboration Board for the execution of the experiment. The term of office is three years and re-election is possible with a 2/3 majority. The spokesperson chairs the executive board, which comprises system and main activity project leaders as well as a technical and a resource coordinator. The technical coordinator ensures an overview of all technical matters and their coherence. The resource coordinator oversees all resources and their optimal use for the collaboration. The Collaboration Board approves the Executive Board, its remit and composition. Members are elected for two years, renewable with a 2/3 majority.

[37] From: ATLAS Collaboration, "Memorandum of Understanding for Collaboration in the Construction of the ATLAS Detector"; CERN RRB-D 98-44rev. CERN Archives, restricted access. All construction MoUs of the other LHC experiments were of a similar format; they were followed by "Maintenance and Operation-MoUs."

[38] ATLAS is taken as an example, cf. footnote 34.

28.3 Open Communication: Global Collaboration to Address Complex Science Issues

Conceiving, constructing, operating, maintaining and scientifically exploiting an experiment such as ATLAS or CMS is a complex science issue. We shall use ATLAS to describe the collaborative work that produces and exploits such an experiment. CMS and other collider experiments operate in a very similar fashion. We start with a brief description of the apparatus as presented in Figure 28.5.

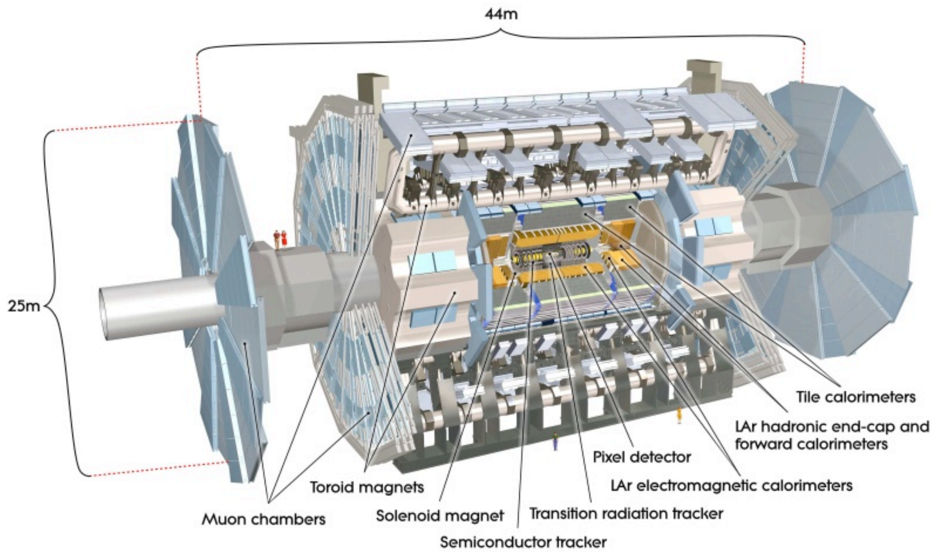

Figure 28.5: Cutaway view of the ATLAS detector. The detector is 25m in height and 44m in length (note the two persons as an indication of size). The overall weight of the detector is approximately 7000 tonnes. (CERN-GE-0803012 05 ©CERN)

The circulating beams of the LHC pass through the center of ATLAS in a vacuum chamber along its axis. Collisions occur inside the "pixel detector." There are one billion collisions per second (10^9/sec) at design rate, each producing around 100 particles. The detector consists of successive shells of detection systems that measure first the position, direction and momentum of all ionizing particles emerging from the collision, then the energy and direction of electrons and photons, then of the hadrons and finally of the muons. The direction and energy of (non-interacting) neutrinos are inferred from missing transverse momentum in the whole event. Momentum measurements require large superconducting magnets creating strong magnetic fields in the tracking detectors. Every detector shell, cable, electronic readout, support structure or magnet element influences the overall precision of the whole device. Therefore, every piece of material inside the experiment needs to be optimized with respect to specific and overall performance. There are millions of pieces.

There are about 100 million electronic detection elements capable of making sense of more than 100 billion particles/sec passing through the experiment during operation. The experiment is capable of selecting online 100–200 events/sec out of the one billion events/sec occurring according to predetermined criteria, mostly large amounts of energy deposited in the detector at large angles away from the incoming beams. This corresponds to a data rate of several hundred megabytes/sec, which are stored for later detailed analysis. Altogether, each experiment creates about 10 million gigabytes or 10 petabytes of already highly selected 'raw' data per year from which the new physics is then extracted.

To give a technology timeline, the mid-1980s—the time of the first ideas about what would later become ATLAS—saw the first Apple Macintosh and the first Windows PCs with the Intel 32 bit 386 CPU rated at 16 MHz and a hard-disc drive of 20 MB. The digital content of the entire world was some 20–100 Petabytes.[39] In the mid-late 1980s, workshops on the upcoming accelerator and experiment projects were held. The discussions on detectors, accelerator designs and conditions for experimentation, data acquisition, event generation and simulation within particular detectors and data analysis attracted the attention of many hundreds of scientists.

In August 1987, CERN Council received the report of the long-range planning committee to the CERN Council (CERN 1987) considering the options to open the center of mass range for colliding partons of order one TeV, an order of magnitude more than was possible at the time. It consisted of descriptions of a large hadron collider, LHC, in the CERN LEP tunnel, a large electron positron linear collider, CLIC, a description of potentially interesting physics subjects in the one TeV (constituent collisions) domain and first considerations of the challenges for various parts of experimental apparatus from the mentioned workshops. The design of the LHC accelerator shown presented difficulties due to the size, cost, high magnetic fields and very high beam currents, but proponents considered these to be manageable within the accelerator and technical departments of CERN, given the resources for well-organized R&D work.

In contrast, the main experimental challenge was to make a general-purpose detector able to handle the unprecedented data rates and to distinguish wanted signals of new physics in the presence of a large variety of more standard processes. At that time, existing detectors were capable of addressing rates that were at best two to three orders of magnitude smaller, their granularity or the number of channels again two orders of magnitude lower and with orders of magnitude with lower response and recovery times. Furthermore, the amount of ambient radiation

[39]See the next section 28.4.

when operating the accelerator asked for radiation-hard electronics that did not exist at affordable cost.

Today, the LHC accelerator and the ATLAS and CMS general-purpose experiments exist and operate according the specifications of the early 1990s based on the R&D work undertaken since 1985 and exponential technology advances in electronics, data storage and networking. The very different configuration of ATLAS and CMS at similar overall performance demonstrates that there are several possible solutions to meet the requirements of identifying new physics.

What we see in Figure 28.5 is a large and complex device consisting of millions of parts fitting tightly together. Today, we can see the publication of first results (ATLAS Collaboration 2010; The CMS Collaboration 2010). These are the finished products of two decades of work by 2000–3000 scientists and engineers. This is like watching a main stem river flowing out to sea but being unaware of the countless tributaries flowing in from the many directions and places that have created it. We may assume that the large river diverges again into a number of distributaries, where groups of scientists follow up diverse science subjects or upgrades of the experiment.

How do scientists proceed from first ideas to operating devices that fulfill the original specifications using available resources within a given time? In workshops that took place in the mid to late 1980s, a number of persons with excellent track records from previous experiments invited open and transparent groups of people to co-develop first ideas for novel general-purpose experimental systems. To meet the LHC physics discovery requirements, in numerous iterations they established combinations of potential subsystems from simulations of hypothetical new particles and their detectable decays, embedded into large numbers of more conventional events. Such activities established the required granularity and detection precision of all parts of the detector, setting high-level specifications and optimizing possible overall configurations for the future experiment by successive iterations.

Further iterations concerned, among many other issues, subsystems, looping through choices of detectors, achievable granularity, ease of absolute calibration, available fast, low power and radiation hard electronics, data readout and cables, power requirements, mechanical containers, positioning and obstructions to other parts of the experiment. In a variety and succession of meetings, the scientists involved reported the results which involved all levels of the experiment, from overall considerations down to technical details. Many ideas were discarded, although elements of these were sometimes retained and integrated into further efforts.

A transparent, horizontal, parallel, interactive and iterative multi-technological process looping and iterating through many parallel project designs and system developments was the obvious organizational choice for the participants. Given the unprecedented amount of new and breaking requirements, many competent persons had to work together and compete for the best solutions. Leadership style at all levels was more about stewardship—encouraging participation and crystallizing good ideas in agreement with overall objectives rather than dictating and directing project evolution (Marchand and Margery 2009). The activity leaders were persons of recognized and acknowledged competencies. In the beginning, there was no question of applying traditional project management procedures with their distinct steps of requirements, design, implementation, verification, operation and maintenance, each step following the next like water cascading down steps: many technologies did not even exist in applicable form at the time when, for example, detector choices had to be made. Such project management procedures were exercised only for production when all ideas had been clarified.

The hierarchical structures normally attached to project management seemed to be inadequate. The participants were highly motivated by the scientific objectives, by the competition for best ideas, concepts or technologies, taking note of their increased powers of development enabled by collaborating with many colleagues with a large variety of skills. The prerequisites for such useful collaborations were openness, competence, tolerance, patience, trust, common interests and objectives as well as respect and hard work. Communicating under such conditions produces novel and excellent solutions.[40]

After several years of brainstorming and intense R&D efforts, four proto-collaborations formulated four initial letters of intent to construct a general-purpose experiment and submitted them to the CERN LHC experiments committee, LHCC, the peer review committe set up to advise CERN management on the quality of the proposed experiments. The LHCC together with CERN management found the four letters of intent to be still inadequate, but a good starting point. They asked proponents to further unite efforts and concepts as only two of the experiments were able to obtain the required resources within the community and from CERN. Two collaborations, ATLAS and CMS, emerged from the previous four, losing some collaborators and acquiring new ones. The CERN management invited the proponents to present technical proposals by the end of 1994. In 1996, they approved ATLAS and CMS for construction on the condition that technical design reports would be elaborated for all relevant components.

Even at that point, the experiments never exited the cycle of continuous communication as new facets of the overall enterprise became important. This is the reason why ATLAS (CMS) had around 40,000 (23,000) well-prepared meetings in the period 2006–2010, with almost 190,000 (120,000) documented contributions.[41] These are the years of ending construction, of commissioning, of preparing for and

[40]On individuals elaborating new ideas in a friendly and consenting environment, see the work of the German poet Heinrich von Kleist (1777–1811): "Wenn Du etwas wissen willst, und es durch Meditation nicht finden kannst, so rate ich Dir, lieber, sinnreicher Freund, mit dem nächsten Bekannten, der Dir aufstößt, darüber zu sprechen [...] Der Franzose sagt l'appetit vient en mangeant, und dieser Erfahrungssatz bleibt wahr, wenn man ihn parodiert und sagt, l'idée vient en parlant" (von Kleist 2008).

[41]The management tool INDICO is described in (Gonzélez et al. 2010). The values quoted above can only be read from an ATLAS or CERN account.

of taking first data and publishing first results. There is no other method for gathering all relevant opinions and studies than by continually presenting all of the details until everything is clear and completely accepted by everyone involved. It is also an excellent way of avoiding errors, pitfalls and unexpected surprises.

The subjects of such meetings and their numbers (in brackets) in the ATLAS collaboration ranged from ATLAS weeks (42), Collaboration Board (25), Executive Board (112), Computing (4600), Inner Detector (3000), Liquid Argon Calorimeter (2400), Tile Calorimeter (1400), Muon Spectrometer (2200), Operation (1300), Physics (5600), National and Institute Meetings (11,800), Trigger and Data Acquisition (3600), Upgrades for high luminosity (1100) and many others, for example, the Combined Statistics Forum of ATLAS and CMS (13). All meetings had numerous local participants and numerous others joining in with contributions and comments by video or Internet from their home institutions. The open, all-encompassing communication culture of particle physics is one of its greatest achievements and *conditio sine qua non* for the progress of this science.

28.4 Information and Communication Technologies (ICT) Infrastructure in Particle Physics

In his address to launch the UK e-Science programme in 2001, John Taylor, former Director General of the UK Research Councils, declared:

> E-Science is about global collaboration in key areas of science, and the next generation of infrastructure that will enable it. [...] E-Science will change the dynamics of the way science is undertaken.[42]

An all-encompassing communication, worldwide collaboration, common production and use of data and its complete analysis requires a powerful, supporting ICT-infrastructure. Driven by the needs of their science, particle physicists have employed state-of-the-art technologies in many fields and are among the most demanding and expert users—and even providers—of information and communication technologies.

It was the "web-like structure of CERN"[43] which helped Tim Berners Lee to develop the World Wide Web at CERN around 1990. This information accession and retrieval service on the Internet brought about a revolution in the accessibility of information and knowledge.[44] The Web has greatly advanced the way science is undertaken.

In 2001 after an in-depth, two-year-long review of all the computing requirements of the experiments[45] CERN launched a worldwide computing project called

[42]E-science in the UK as described by its first programme director Tony Hey in *Science* magazine (Hey and Trefethen 2005).
[43]From (Berners Lee and Fischetti 1999, 9). For more background information, see also (Gillies and Cailliau 2000).
[44]His first website was *info.cern.ch*.
[45]See (Bethke et al. 2001).

LHC Computing Grid (LCG).[46] The objective of the project was to provide equal opportunities for data analysis to all scientists participating in the LHC experiments, regardless of the location of their home institutes.

In contrast to the original Web and Web services, which enabled easy access to continuous information, Grids[47] and Grid services in addition enable data and information to be processed within the grid and the results made directly available to the collaborators. Accessing and protecting original and derived data requires strict procedures and access-authorizations by their owners, the collaborators.

Many CERN member states supported the LCG on an ad hoc basis. The LCG's efforts and interest in other sciences have now given rise to a study for a future European Grid Infrastructure (EGI)[48] which is based on national grid initiatives in the EU and feeds into the European e-Infrastructure[49] considerations, US Cyber-infrastructure[50] and similar projects in many other countries.

Today, the Worldwide LHC Computing Grid (WLCG) is a global collaboration of more than 170 computing centers in thirty-four countries with more than 100,000 processors and a ~10-petabyte storage capacity of tape and disc, initially supported by the four LHC experiments and several national and international grid projects.[51] The mission of the WLCG project is to build and maintain a data-storage and data-analysis service infrastructure for the entire high-energy physics community using the Large Hadron Collider at CERN. The WLCG project anticipates operating between 500,000 to 1,000,000 tasks per day and expects 15 petabytes of data from LHC experiments to be stored and processed per year. The first results of the LHC experiments have been published using WLCG resources to the complete satisfaction of the users.

In this context, it may be interesting to compare the LHC experiments' design data rates to all digital data produced and stored yearly on the planet. LHC experiments plan to store 15 petabytes/ year (15 x 10^{15} bytes/ year). We can compare this amount to all data created, replicated and stored worldwide in 2010, around 1000 exabytes[52]—a tenfold increase every five years since many years. Calculating backwards twenty years or four orders of magnitude down to the time of conceiving LHC experiments in 1990, the design data storage of LHC was then at the level of 10% of the total. Interestingly, the present edition of the *Review*

[46] LCG: http://lcg.web.cern.ch/LCG.

[47] See (Foster et al. 2001); see also http://www.globus.org.

[48] European Grid Infrastructure study: http://knowledge.eu-egi.eu/knowledge/index.php/Main_Page. In the wake of LCG and to obtain resources from the European Commission several successive EU grid projects were undertaken under CERN leadership, such as Enabling Grids for E-science in Europe (EGEE): http://www.eu-egee.org. The corresponding US effort is the Open Science Grid (OSG): http://www.opensciencegrid.org.

[49] See http://cordis.europa.eu/fp7/ict/e-infrastructure/home_en.html and http://knowledge.eu-egi.eu/knowledge/index.php/Main_Page.

[50] Report of the National Science Foundation Blue-Ribbon Advisory Panel on Cyberinfrastructure: http://www.nsf.gov/od/oci/reports/toc.jsp.

[51] Figures taken from the LCG web: http://lcg.web.cern.ch/lcg.

[52] From Wikipedia 'Zettabyte': http://en.wikipedia.org/wiki/Zettabyte.

of Particle Properties (Particle Data Group Particle Data Group) for over fifty years the top-level summary of what is known in particle physics, is a 40MB file and the LHC petabytes will be condensed into future editions of that review. However, there is much more to science than high-level summaries.

What else should the scientists preserve and make generally available besides the abstract summary conclusions of the *Review of Particle Properties*, the studies performed, and the technologies developed and combined into powerful devices? All of these have enabled scientists to produce and observe interesting collisions, to observe and record relevant data, analysing it to advance their science.

To address this question, we can summarize what is being recorded. Experiments and accelerators document their detailed technical information in an engineering and equipment data management system, in internal notes and information services, tutorials, technical proposals, design reports and presentations and minutes of meetings. Official releases are made in instrumentation, technological and physics conferences and proceedings as well as in publications in appropriate journals and scientific reviews. There are thousands of theses written on technological and scientific investigations. Accelerator laboratories organize topical schools on important subjects and record them. They also offer academic training lectures and student courses.

To turn only to CERN, its Scientific Information Service (SIS) runs, among other operations, since 1990 an online library, the CERN Document Server (CDS)[53] currently holding a million bibliographic records of which almost half are full-text documents concerning particle physics and related areas. CERN's publication policy stipulates that every effort will be made to publish papers under open access (OA) conditions, as defined by the SCOAP3 initiative.[54] As of the date of this document, 2007, the Creative Commons Attribution ("cc by") license[55] meets these conditions. All papers will mention "Copyright CERN, for the benefit of the Collaboration." CERN will strive to exercise its copyright in such a way as to permit the widest possible dissemination and use of its publications. Every reasonable effort will be made to avoid transfer of copyright to a third party. In terms of the OA discussions, CERN mandates "Green OA" and strives to achieve "Gold OA." Green OA is achieved well beyond the 90% level.

The CERN Scientific Information Policy Board (SIPB) is mandated to look into the preservation of scientific objects and records, meaning physical objects or their representations and also "original data." A first report on a particle physics survey on data preservation, re-use and (open) access has been published.[56] The report states the growing interest in preserving relevant samples of event data. The

[53] An overview of the contents of CDS is given at: http://cdsweb.cern.ch.

[54] "Sponsoring Consortium for Open Access Publishing in Particle Physics" (SCOAP3): http://scoap3.org/about.html and "CERN Publication Policy Open Access and Copyright for the LHC publications" http://library.web.cern.ch/library/OpenAccess/PublicationPolicy.html.

[55] For the attribution license of creative commons, see: http://creativecommons.org/licenses/by/2.0.

[56] For the first results from the PARSE.Insight project, see (Holzner et al. 2009).

greatest challenge is to give a meaningful presentation of the best data produced by the Collaboration. It is also difficult to find the resources to undertake such work. To give an example, years ago many tons of exposed bubble chamber film was given to a chemical firm to extract the silver from the emulsion for resale. Because the measuring tables for precision track measurements no longer existed and calibration data had been lost, it was decided that there was no apparent interest in the community to keep and preserve the film.

Most of the information and data mentioned above is available in digital form. What is missing is a coherent and, most importantly, persistent online-structure for all of this information, as well as powerful search engines and the resources to bring it together. This encompasses high level reviews to experimental-device details and original data sets with a view to make all of this knowledge generally available and to archive and curate the information for long-term use.

28.5 Conclusions

Scientific and technical knowledge is a special commodity, and consuming or sharing this knowledge neither reduces nor impairs it. Most importantly, generally and openly sharing knowledge in its proper context increases the knowledge base of all, fertilizes the creation of new knowledge in new applications, and thus with use the value and applicability of knowledge is increased.

For over sixty years, particle physics has been producing interesting and relevant scientific results within a global community that aggregates in powerful international collaborations that are able to address the most difficult challenges together. Due to its fundamental scientific goals, which are rooted in the tradition of eminent physical scientists of past centuries, and its spectacular facilities and global collaborations, particle physics draws excellent young people to science. They learn skills that are highly appreciated in numerous industries, in other sciences and as well in education.

With its exceptional skills in information and communication technologies and its almost complete openness in disseminating its findings, the particle physics community should engage in even more powerful, structured and curated knowledge dissemination schemes for all its current science and technology, publications, historical records, relevant 'original'-data and other insights. The *Particle Data Group* collaboration could serve as an organizational example since it has been compiling state-of-the-art particle properties in a permanent review for over fifty years.

We have described the collaborative knowledge acquisition process of particle physics, the complete analysis of all data and the reduction properties of physical objects within theoretical frames. We have further described collaborations with clear common goals, critical mass, open sharing and communication and elaborate quality assurance as the most successful and efficient entities for obtaining significant progress in a fundamental science. In particle physics, the authors are acknowledged for their intellectual property, but content is shared freely in the interest of progressing rapidly toward challenging goals within given resources and time spans. It would be advantageous to apply the process to other sciences and interdisciplinary ventures, in particular, using the evolving and enabling "e-infrastructures."

Making the technological achievements of particle physics useful for applications in other sciences and in industry forms part of CERN's Convention to make its work generally available. Interdisciplinary use of such knowledge, skills, know-how or best practices, however, is quite difficult, mostly since resources are normally science specific. The most promising manner of applying the technologies of particle physics is the adoption of interdisciplinary collaborations that are sufficiently long-term for people to learn how to collaborate efficiently with each other.

Finally, a world "knowledge society" that applies the open sharing and availability of knowledge in a respectful and collaborative way would more rapidly advance many burning issues such as sustainable energies, climate, environment, health, development and even sciences.[57]

A European Commissioner responsible for Development once said:

> It is not the impossible which gives cause for despair but the failure to achieve the possible.

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[57]The views presented here are those of the author and do not necessarily represent CERN's or other particle physics institutes' views.

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Chapter 29
Internationalism and the History of Molecular Biology

Hans-Jörg Rheinberger

29.1 Introduction

The history of molecular biology has been told a number of times over the past three decades, and its historiography has thereby experienced a number of reorientations.[1] Questions of periodization, as usual, have been and still are a matter of debate, but most observers will probably agree that the history of molecular biology can be conveniently divided into three major phases. The first is marked by a new conjuncture of physics, chemistry, and biology, roughly between 1930 and 1950. It was characterized by a set of innovative research technologies, with a focus on protein analysis and genetics. The second spanned approximately the decades between 1950 and 1970, extending from the physical elucidation of the structure of the DNA double helix, through its climax, the biochemical deciphering of the genetic code in the early 1960s, to its eclipse, the advent of a properly molecular biological gene technology in the early 1970s. The third phase took its starting point from the construction of the first transgenic DNA molecules in the early 1970s and resulted a decade later in the human genome project. Gene technical biology has since become the science of a thoroughly constructive and synthetic manipulation of living cells at the molecular level of hereditary instruction.

The history of molecular biology has many facets. According to the theme of this volume, I will concentrate on the *international* aspects of its development. Internationalism took distinctively different forms within the three periods mentioned above. These different forms are, on the one hand, intimately connected to the changing national and international political contexts: the interwar period and World War II; the Cold War era; and the time of post-communist globalization. On the other hand, they are at the same time an epistemic function of the evolving and diversifying objects of molecular biology.

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[1]This paper was presented at the XXII International Congress of History of Science, Beijing, 23–30 July 2005, Symposium 3 *History of International Scientific Collaborations.* An earlier version of it has been published in *Annals of the History and philosophy of Biology* 11 (2007): 249–254.

29.2 The Early Years: 1930s and 1940s

First, we will look at the 1930s and the 1940s. It has repeatedly been pointed out by historians of science that philanthropic institutions—in particular the Rockefeller Foundation with its head of the natural sciences division, Warren Weaver—played a vital role in the early days of setting the stage for what was to become molecular biology. As Pnina Abir-Am (1993), Robert Kohler (1991) and others have argued, Weaver was dedicated to fostering transdisciplinary research on what he then called "vital processes" and he did so by funding physicists, chemists and mathematicians who were willing to engage with biological questions and, moreover, to direct their often novel research instruments toward biological objects. Protein research and genetics were in the foreground of his research agenda. He not only thought in interdisciplinary but also in international categories. Through Wilbur Tisdale and Harry Miller, the Rockefeller Foundation officers in Paris, Weaver spun a network of funding that went far beyond the United States and included interdisciplinary collaborations in post First World War Europe's major research sites as well. The Rockefeller Foundation thus vitally contributed to re-establishing international scientific bonds that had been broken by the hostilities of World War I and the immediate postwar turmoils. Most of the individual research projects during this time, however, featured local collaborations and were not international in themselves. In order to compensate for this deficit, the Rockefeller Foundation sponsored international workshops and conferences. In addition, through its fellowship program, it funded young European scholars to spend a postdoctoral year in major American or other European laboratories.

When the Nazis came to power in Germany and initiated an unprecedented exodus of Jewish and politically liberal and leftist scientists from Germany and other European countries to be occupied by Nazi Germany or having fascist governments themselves, the Rockefeller Foundation helped many of them to settle in their new surroundings. It can be stated that this exodus, in a way, initiated a kind of compulsory internationalism that had a deep impact on the early history of molecular biology. A cursory look at the roster of persons who count among the founders of the new biology shows that many of the leading figures of the first generation were either enforced or voluntary émigrés: Erwin Chargaff, a chemist from Czernowitz at Columbia University; Max Delbrück, a physicist from Berlin at the California Institute of Technology (Rockefeller fellowship); Salvador Luria, a medical doctor from Turin at the University of Indiana (Guggenheim fellowship) and then at the University of Illinois; Severo Ochoa, a medical doctor from Asturia at the University of New York; Max Perutz, a chemist from Vienna at Cambridge, England; Gunther Stent, a refugee from Berlin and later a physical chemist at Berkeley, and many others as well. This traffic was one-way however; the following World War II resulted in a thorough international isolation of a substantial part of the European continent's scientists, and this not only in the realm of emerging molecular biology.

There is also an epistemic aspect to internationality in this early phase in the history of molecular biology. As already mentioned, it rested technically on an array of new analytical instrumentation, such as ultracentrifugation, electron microscopy, electrophoresis, X-ray crystallography, UV-spectroscopy and other sophisticated apparatus targeted at allowing diverse phenomena of life to be tackled at a macromolecular level. Initially, there were only a few privileged places where these different instruments were constructed and eventually put to biological use. This also meant that the knowledge going into their operation was thoroughly local, if not monopolized by one research team, at least for a certain period of time. In this phase of technological development, the instruments did not travel; rather, the people who wanted to construct or learn to work with these instruments had to travel, thereby crossing national boundaries—and disciplinary boundaries as well, since the operation of most of these instruments intrinsically necessitated a collaboration between physicists, chemists and biologists. Protein crystallography was particularly strong in Cambridge, England and at the California Institute of Technology; ultracentrifugation in Uppsala; UV-spectroscopy in Stockholm and New York; electron microscopy at RCA's New Jersey laboratories, just to give a few examples. As we will see, this epistemic situation continued over the first decade after World War II. It was not until the late 1950s that these technologies became black-boxed and began to spread widely.

29.3 The Immediate Post World War II Period

After World War II, the political situation in the Western world changed radically.[2] With respect to molecular biology, within a few years an international network of researchers formed and organized itself around a few centers, among them the phage group with Max Delbrück at Caltech and Cold Spring Harbor with its annual phage course, the Medical Research Council Unit for the Study of Molecular Structure of Biological Systems around Max Perutz and John Kendrew in Cambridge, the Pasteur Institute around Jacques Monod and André Lwoff in Paris, but also less well-known ones such as the electron microscopy unit organized around Jean Weigle at the University of Geneva, or the Rouge-Cloître group of biologists, physicists and biochemists around Jean Brachet at the University of Brussels. There were frequent personal exchanges among these groups. Postdoctoral visits across the Atlantic resumed and international scientific figures like Leo Szilard, a newcomer to the field, promoted the new biology on their relentless travels. These exchanges temporarily slowed down at the height of the Cold War

[2] The historiography of molecular biology in the Soviet Empire is still in its early stages, see (Abdrakhmanov 2006, 333–339). Another story would have to be written here, a story of failed internationalism in science as a result of the Cold War.

at the beginning of the 1950s, where, for example, Linus Pauling was forbidden to travel to Europe and Jacques Monod was denied a visa to enter the United States.

The particular history of each of the groups mentioned above is, meanwhile, well-documented with case studies by Lily Kay (1993) on Caltech, Jean-Paul Gaudillière (2002b) on Paris, Soraya de Chadarevian (2002) on Cambridge, Bruno Strasser (2006) on Geneva, and Denis Thieffry (1997) on Brussels. Rich and abundant material has been accumulated. There is also a recurrent pattern to be found in these studies that appears to be pertinent to this discussion of early molecular biology's internationalism. Soraya de Chadarevian has expressed it for the British center in Cambridge as follows:

> It has been argued that molecular biology—profiting from an increased mobility of people created especially by new science policies and funding schemes in the Cold War era—constituted itself in an international space (Abir-Am 1993). My view is that the increase in international exchanges modified the relations between local settings, and thus the local settings themselves, but did not do away with them. (de Chadarevian 2002, 247)

For the Institut Pasteur in Paris, Jean-Paul Gaudillière has similarly observed

> a scientific strategy taking as its starting point the exploitation of a local system quite different from the dispositifs privileged in the United States. […] On the one hand, the mobilization of a vast array of human and material resources offered by the United States; on the other hand the preservation of a home-made approach that granted the autonomy and the possibility of an alternative to the bacterial genetics at Caltech, Cold Spring Harbor, or Columbia. (Gaudillière 2002a, 259)

In their assessment of molecular biology in postwar Europe, de Chadarevian and Strasser talk about a "glocal" picture in this respect (de Chadarevian and Strasser 2002).

What does that mean epistemically though? There is a message here that appears to be characteristic of the development of molecular biology in the two and a half decades after World War II, in which the new approach toward the molecular basis of living systems became scientifically visible and during which the tag *molecular biology* was increasingly used for the self-identification and self-vindication of those who wanted to be perceived as partisans and participants in the new biology movement. In this phase, molecular biology formed itself into a patchwork of different experimental systems, often centered around a particular technology, sometimes a big and demanding research instrument such as an electron microscope or an X-ray machine. However, this was not always necessarily so: small scale tools such as radioactive tracing or biochemical in vivo and in vitro assays were equally important—and also just as demanding in their fine-tuning.

Together, these experimental systems formed a landscape of experimentation, with neighboring systems sharing material constituents, and with only indirect links to systems further away. It resulted from a differential exploitation of the vast array of research technologies described for the previous period that were initially disconnected from each other, but became increasingly adapted to sophisticated biological applications in various experimental systems and therefore linked to each other. Secondly, it rested on the cultivation of a few distinct model organisms, in particular lower fungi, bacteria and a variety of viruses and phages. Each of these organisms required a certain amount of idiosyncratic manipulative knowledge. On the other hand, the standardization of certain model organisms such as Escherichia coli served as a reference point not only for those who worked with them, but also for those comparing and judging their results obtained from other organisms, and in this way the models also became connected to each other. From a third perspective, the formation of this landscape involved different interdisciplinary skills—biophysical, biochemical, biomedical, biomathematical, in slightly different local combinations.

29.4 The 1950s and Early 1960s

An ideal situation for international circulation had thus been created that resulted in cooperative effects of an unparalleled scale. And, indeed, if we look at the major findings that punctuated the establishment of molecular biology as a new discipline in the course of the 1950s and the early 1960s, we realize that many, if not the most important of them, resulted from international cooperation between two or three individual researchers from different local cultures in different countries. To start with, the elucidation of the structure of the DNA double helix in 1953 was the result of a collaboration in Cambridge between a British scholar, Francis Crick, and an American scholar, Jim Watson, one of them a physicist, the other a biologist by training. The work that led to the identification of messenger RNA was done in Paris by the Pasteurians Jacques Monod and François Jacob in cooperation with Arthur Pardee from Berkeley; at Caltech by Jacob from Paris, Sidney Brenner from Cambridge—himself a South African MD—and Mathew Meselson from Pasadena; at Harvard by François Gros from Paris and James Watson from Cambridge/MA. The deciphering of the first code words happened at the National Institutes of Health in Bethesda and involved the American biochemist Marshall Nirenberg and the German physiologist Heinrich Matthaei. The Swiss physicist Jean Weigle from Geneva published phage work together with Delbrück as well as with Meselson from Pasadena. Frederick Sanger in Cambridge worked on the primary structure of the insulin chain—the first protein to be completely sequenced—together with the Austrian biochemist Hans Tuppy from Vienna. Many more international and interdisciplinary couples such as these could be named here. Throughout the 1950s, they all conveyed to molecular biology its appearance as a paragon of an international science. It was based on distributed, locally embedded resources that lent themselves to being triggered and led to major results by sometimes minor inputs from neighboring, slightly different experimental systems.

Around 1960, the visibility of rising molecular biology had reached the planning circles of European governments and became, to a certain extent, a state affair. Throughout the following decade, molecular biology became a target for national science advancement plans aiming at a reorganization of research and teaching in the life and biomedical sciences. This led to the foundation of molecular biological research institutes in all major European countries. For Germany, it was Max Delbrück who assumed a leading function in the process. The perception of a necessity to balance the perceived American supremacy in the field also gave rise to increasing efforts for advancing molecular biological research at a European level. These efforts finally resulted in the foundation of a European Molecular Biology Organization and eventually a European Molecular Biology Laboratory. John Krige has argued that it was not the distributed character of molecular biological technology—as sometimes purported—that prevented the early establishment of a facility for molecular biology like that of CERN, the European organization and laboratory for particle physics.[3] According to Krige, it was, rather, the perception of national deficits that put the national strengthening of molecular biology first on the agenda of the major European countries, and left a common European laboratory as a matter for the next step (Krige 2002). Arriving at this order of events, however, despite Krige's argument, could, after all, have something to do with the distributed and therefore locally entrenched character as described for what we can call—in view of the subsequent developments—the classical period of molecular biology.

29.5 The Gene Technology Era

Toward the end of this extremely compressed overview of forms of internationalism implied in the development of molecular biology, let me briefly come to the third phase, the era of gene technology. After a few years of self-imposed caution, the recombinant DNA technologies that emerged in the early 1970s in the United States led to a major rearrangement of the field. On the one hand, molecular biology, now in the form of a genetic technology, entered the world of commerce, and with that, of international economic competition. Gene patenting, on the one hand, has brought back constraints for transnational collaboration. On the other hand, the advent of powerful gene sequencing technologies opened up the perspective on projects like the human genome project, which by their very size and nature necessitated a more or less stringent international collaboration, no longer just as a spontaneous activity of individuals, but now as a coordinated effort of the major players of the scientific community. Molecular biology entered the era of global, planned, large-scale collaborations. In parallel, the vast amounts of genomic information resulting from these collaborative enterprises necessitated

[3]See chapter 28.

the construction of new kinds of collectively usable data pools. They have become a major target of bioinformatics of our day, wiring together the contemporary bio-molecular laboratories from all over the world in a virtual space and creating an unprecedented form of scientific communication over an ever-increasing pool of shared information.

However, we also stand before possible applications of gene technology in reproductive biology and genetic germ line intervention that urgently call for international regulations. Today, such regulations are far from being established. Different countries in the world respond to these challenges with quite different rules. An internationalism of a particular slant could result: a kind of science tourism that would lead ambitious scientists who feel themselves restricted by their national regulations choosing work in countries where such restrictions do not apply. Internationalism, after all, is not one singular, well-defined thing or relation. On the contrary, it comes in numerous guises and many variants. The history of molecular biology certainly displays some of the major forms it took throughout the long second half of the twentieth century, and, as we have seen, it combines them with patterns that incorporate shifting global political trends as well as changing epistemic configurations.

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Chapter 30
The Role of Chemistry in the Global Energy Challenge

Robert Schlögl

30.1 Introduction

The fifth oil price shock (Doroodian and Boyd 2003; Kilian 2008; Herrera and Pesavento 2009) started from anticipated shortages in the availability and supply of the most visible energy carrier, and created intensive responses throughout society that have now prevailed for several years. Besides coping with the eco-political issues, for the first time we all feel that the present energy supply system needs some fundamental changes. Both the finite supply of liquid fossil fuels and the high awareness of climate change[1] resulting from our fossil fuel consumption have sensitized society and hence the scientific community as well. Chemistry is reacting more sensitively than in earlier oil crises as it promises critical contributions, in the form of catalysis and material science, to the development of all non-nuclear alternative energy conversion processes on the grid-level scale. This time, however, many other sciences are also reacting to the challenge[2] thus creating a wave of interdisciplinary activity in energy research.

This chapter intends to introduce the reader to a framework of challenges faced by science in approaching energy research. Chemistry is at the forefront of traditional disciplines responding to the challenge of supplying non-fossil regenerative energy. For this reason, the chemical sciences are used to illustrate the underlying challenges posed by the operation of science in a global context. The text exemplifies the technical issues that need to be addressed in some depth. This provides a firm basis for the second part, which presents an essay on the disciplinary strengths and shortcomings of chemistry in the context of energy research (Velden and Lagoze 2009). A personal account of the global aspects is presented rather than a detailed disciplinary critique of the emerging energy-for-chemistry community. It is stressed that energy science is intimately connected with non-scientific issues that exert strong influence on the science and demand a critical reflection by individual scientists on the global and local factors affecting their practical work.

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[1] (Morison and Lawlor 1999; Zachos et al. 2001; Parmesan 2006; Archer and Brovkin 2008; Egan 2009).

[2] (Arico et al. 2005; Balaya 2008; Manthiram et al. 2008; Hu et al. 2009).

Energy research is a broad interdisciplinary topic. A large variety of fundamental approaches are proposed and actively pursued in order to address the different issues of sustainable and safe energy supply strategies. Several reviews[3] deal with the overall strategy for creating an energy mix that introduces many completely novel approaches to energy conversion. As it is clear that energy cannot be created, all approaches amount to a kind of conversion process. Since many of them involve molecular or solid energy carriers, it is evident that chemistry is at the core of the energy challenge. Chemistry provides the processes and materials for energy conversion reactions. Chemical science can control the energetic "cost" of both energy conversion and its utilization. After all, our current fossil energy carriers were created by biochemical processes in photosynthesis and later converted to their present high-density forms by geochemical processes.

This chapter attempts to elucidate the pivotal role of chemistry in actively pursuing the transition from fossil energy scenarios to more sustainable energy supply systems. The equally relevant issues of primary electricity generation, electricity distribution (Beccali et al. 2004; Charles 2009) and strategies for saving energy in our current scenario are not covered here to maintain some clarity in the approach. The role of nuclear fission and fusion technologies is not considered here (see chapter 27). The following text intends to clarify some underlying lines of thought and thus refrains from discussing individual examples for its theses. Examples can be found in the cited literature to illustrate points made in the text, which does not claim to cover the issue in any exhaustive way.

30.2 Energy and Climate

It is now universally recognized that global warming is a large-scale experiment (Parmesan 2006) that mankind started without knowing the boundary conditions and the complexity (Mitchell 1989; Egan 2009) of the interactions in the climate system (see chapter 31). The cause of climate change is the chemical conversion of carbonaceous materials into thermal and derived forms of energy. Not only direct combustion, but also excessive and inadequate land use practices (Paustian et al. 2000; Lal 2004; Cheng et al. 2006) contribute substantially to greenhouse gas emissions. The most important lesson to learn from the evolving situation is not to create alternative or "renewable" energy systems (Smeets et al. 2007) without understanding exactly how they are involved in the complex regulatory systems of our planet. This means that all concepts of future energy conversion must be designed and verified in light of their impact on the various biological and physico-chemical regulatory systems on Earth. The often used word "sustainability" contains not only a term describing the balance between input of energy

[3] (Islam et al. 2004; Ghanadan and Koomey 2005; da Silva et al. 2005; Nath and Das 2007; Cosmi et al. 2009; Shaahid and El-Amin 2009).

carriers and output of waste, but also a kinetic term[4] describing the time constant of equilibration between input and output. Neglecting this kinetic term caused the climate change problem to arise. Great care is needed when energy scenarios are classified as "renewable" or "regenerable," as much less obvious (Berntsen et al. 2006; Montenegro et al. 2007) unwanted consequences than the emission of carbon dioxide can arise from large-scale chemical conversions of energy carriers. Typical examples are the consequences of energy farming for biodiversity, the residence time of emitted carbon dioxide in the atmosphere over various ecosystems,[5] or the consequences of large-scale deposition of carbon dioxide in deep seawater or in aquifers underground (Ketzer et al. 2009; de Best-Waldhober et al. 2009).

In the essay part of the chapter, the term sustainability will also be used to describe a quality of research conduct. Energy science is sustainable for science only if validated understanding or reliable basic knowledge for technologies can be extracted from it. This hypothesis generates multiple consequences for individuals and the scientific community as a whole.

It is most relevant to consider energy conversion scenarios as hierarchical systems of process chains encompassing the generation of energy carriers, the conversion of energy carriers, the management of the waste products and effects of using of the energy liberated. A typical example of the complexity of interactions was the recent price explosion for foodstuffs caused by the still small-scale sector of energy farming (Muller 2009). This example highlights that not only scientific factors, but also socio-political ones (Voorspools 2004) are of decisive influence on the evolution of the energy challenge. These implications are not discussed in the present work, although some basic assumptions influence the construction of plausible energy scenarios described below.

Even for purely chemical considerations, the systemic approach demands not only considerations about the efficiency, security and sustainability of the processes, but also about the availability of critical materials for the intended scale of use. In this respect, the application of noble metals or their compounds is a critical issue, exemplified by the use of Pt and Ru. For all grid-scale sustainable applications, chemistry has to provide solutions that circumvent the use of such elements or minimize their application to an absolutely essential minimum. The extent to which this is possible is not yet clear, as only limited systematic approaches have been applied (Greeley et al. 2006; Greeley and Norskov 2007), despite phenomenological approaches like high-throughput screening (Woodhouse and Parkinson 2009). A promising development (Kanan and Nocera 2008; Kanan et al. 2009) is the simple creation of a complex molecular electrocatalyst based on Co-phosphate species. The highly dynamic character of this system capable of oxygen evolution is reminiscent of the dynamics of the phosphate catalysts (Havecker et al. 2003; Conte et al. 2006) used for the inverse process of catalytic selective ox-

[4](Berntsen et al. 2006; Montenegro et al. 2007; Archer and Brovkin 2008; Van Hise 2008; Hofmann et al. 2009).

[5](Montenegro et al. 2007; Archer and Brovkin 2008; Van Hise 2008; Hofmann et al. 2009).

idation. The deliberate exploitation of structural dynamics for a catalytic system is considered to be a guiding principle for finding novel material solutions that can be used under the constraints of sustainable energy conversion.

The already significant modification of the climate through CO_2 emission calls for a most rapid reduction of further emissions. Chemistry can contribute to this task in multiple ways as discussed below, but few of these contributions will be significant on the scale of present emissions within short timescales of below one decade. The fastest method would be to reduce emissions by saving energy through existing technologies and behavioral adaptations. Large emission savings also can be realized by immediately using the already existing solutions to improve the efficiency of thermal energy conversion, even if this requires the rapid replacement of fossil power stations. This measure must be supported by intelligent management of distribution grids (Charles 2009; Shaahid and El-Amin 2009), allowing the initial production of primary electricity to be utilized. These measures can buy time to allow chemistry to develop and implement the measures described below. It is unrealistic to promise that rapid and large-scale novel solutions from chemistry will solve the energy challenge in the immediate future.

30.3 The Scale of the Energy Challenge

Global consumption of primary energy is about 5×10^{14} MJ/a. This very large number contains the net energy used plus an estimated 30% contribution for losses during energy conversion. In Germany in 2007, the losses amounted to 4307×10^{12} kW (url BMwi energy), against a total crude oil consumption of 4678×10^{12} kW. These numbers indicate that any effort to reduce losses from converting energy carriers is of great relevance for energy scenarios today and in the future. Chemistry can play a limited but relevant role in this endeavor by maximizing the selectivity of molecular transformations and by helping to minimize physical losses through the development of appropriate materials (high-temperature materials, solid-state lighting).

To get a feeling for the dimension of energy requirements, the following "Gedankenexperiment" is suggested. The energy content of hydrogen gas at 200 bar pressure in a process that burns it with pure oxygen to gaseous water is 530 kWh/m^3 gas. This is equivalent to roughly 2×10^3 MJ. To satisfy the global energy demand, we would need 2.5×10^{11} m^3 hydrogen gas. This is roughly equivalent to the capacity of all storage caverns for natural gas on the planet. More tangible is the equivalence of this amount of hydrogen to the number of 5×10^{12} laboratory gas cylinders of hydrogen that we consume per year. Knowing that about 1.5×10^9 people consume 75% of this energy, we learn that, statistically, in the first world about six hydrogen gas cylinders are consumed each day. The socio-political dimension of this consideration becomes apparent when we conclude that the majority of the global population is left with a consumption rate of about 0.9 cylinders per day.

The purpose of this example, which does not include any growth in energy demand, is to illustrate the enormous challenge for any new energy supply technology. It shows that we cannot afford to develop just one technology, but that we must use every approach that fulfills the criteria of sustainability described above. The dimension of energy demand further illustrates the enormous sizes of the technological installations required as well as the capital needed to construct them. Both factors further imply that the timescale for such a replacement of fossil energy to sustainable scenarios must be on the order of decades. This implies that we will need a phased approach in which several scenarios provide for a gradual transformation, and that in any phase there must be enough room to adjust for technological improvements based on future scientific breakthroughs without endangering the efforts and funds already invested.

The scale of chemical conversions for energy is roughly twenty times larger than the scale of the global chemical industry. When we create new processes, it is thus important not only to be as effective as possible, but also to consider the scalability of a process both in terms of its material requirements and its unit operations. The design strategy of chemical plants has provided an excellent toolbox (Van den Heever and Grossmann 1999) for estimating such aspects of any new processes already in early stages of development. This practice should also be implemented in the search for energy solutions.

This paper does not aspire to describe all of the many approaches towards energy conversion[6] that chemists have described over the years, and especially recently in response to the general awareness of the energy challenge. Instead, it focuses on the contributions expected from chemistry to initiate technologically the restructuring of our present energy scenario. Many of the novel approaches, such as those intending to design the "artificial leaf" (Lubitz et al. 2008), are still far from becoming relevant to grid-scale technologies, and many of these approaches will face problems with fulfilling the criteria for sustainability (Voorspools 2004; Alanne and Saari 2006) when considered as technological systems. Some of them will overcome all of these obstacles to become advanced generations of energy conversion technologies and contribute to future energy scenarios. It is thus detrimental to the total effort to preselect the topics on which energy research should concentrate. Chemical energy research should enable the identification and verification of ingenious concepts of chemical conversion and of materials that create new technologies.

On the other hand, it is necessary to focus to a certain extent on those issues[7] that are critical for the near or foreseeable future. Many of them concern the conversion of solar energy into a storable energy carrier.[8] Storing primary energy in energy carrier chemicals and/or battery electrodes (Tarascon and Armand 2001;

[6] (Voorspools 2004; Ni et al. 2007; Deshmukh and Deshmukh 2008; Khan et al. 2008).

[7] (Herbert et al. 2007; Deshmukh and Deshmukh 2008; Khan et al. 2008; Ramachandra 2009).

[8] (Hall 1978; Bolton and Hall 1979; Bak et al. 2002; Kodama 2003; Aroutiounian et al. 2005; Umeyama and Imahori 2008).

Wakihara 2001) has the advantage of providing for simple recovery of electrical energy. What appears to be most critical is to enable the transition from purely fossil energy systems to a mixed constellation with an increasing contribution by renewable energy to allow fossil fuel technologies to be phased out (such as saving on building or rebuilding thermal power stations). It is the purpose of this paper to propose a rational approach of selecting some of these focal challenges for chemistry. This approach consists in assuming generalized energy supply scenarios and analyzing the resulting systems network in terms of bottlenecks. Fundamental research challenges result from this analysis of how to circumvent such bottlenecks on a large scale while observing the boundary conditions of sustainability and climate compatibility outlined above.

30.4 Energy and Chemistry: EnerChem

Chemistry is the strategic core discipline for all future energy conversion processes based upon primary solar energy. In addition, chemistry is indispensable to all efforts to save energy by performing our technical production processes with optimized utilization of resources. Not only energy conversion from fossil sources, but also many material production processes, benefit from improved chemical reactions and from optimized processes, frequently achieved through optimized catalysts. Material science contributes to energy savings in many additional ways, enabling more energy-efficient processes such as home air conditioning, high-temperature combustion, solid-state lighting and more efficient transportation. Electrical energy storage in Li-ion or redox flow batteries requires redoubled efforts from chemistry to design functional electrodes and storage materials.

A rough outline of the multiple role of chemistry is given in Figure 30.1. Material developments fall within all synthetic disciplines of chemistry, ranging from supramolecular and organic chemistry (lighting, molecular electronics, organic solar cells) over metal-organic chemistry (selective chemo catalysis of complex molecules, MOCVD processes for solar cells) to inorganic metals and ceramic chemistry. Catalysis plays the pivotal role among the process development efforts. This science deals with the control of energy barriers and thus allows the design of reactions with high selectivity and rapid performance. Heterogeneous and electro-catalysis will be the workhorses of the initial generations of energy conversion systems. Molecular catalysis in artificial or biological systems may, however, increasingly contribute not only to effective transformations of energy storage systems, but in later generations of energy systems perhaps even to direct solar light conversion through photocatalytic systems.[9] Bio-catalytic processes will be relevant to the safe sequestration of CO_2, as they use direct solar energy to convert gaseous diluted CO_2 into carbon-dense precursor materials for safe and useful deposition.

[9] (Gratzel 1981; Meyer 1989; Milliron et al. 2004; Alstrum-Acevedo et al. 2005; Kanan and Nocera 2008; Barber 2009; Yagi et al. 2009).

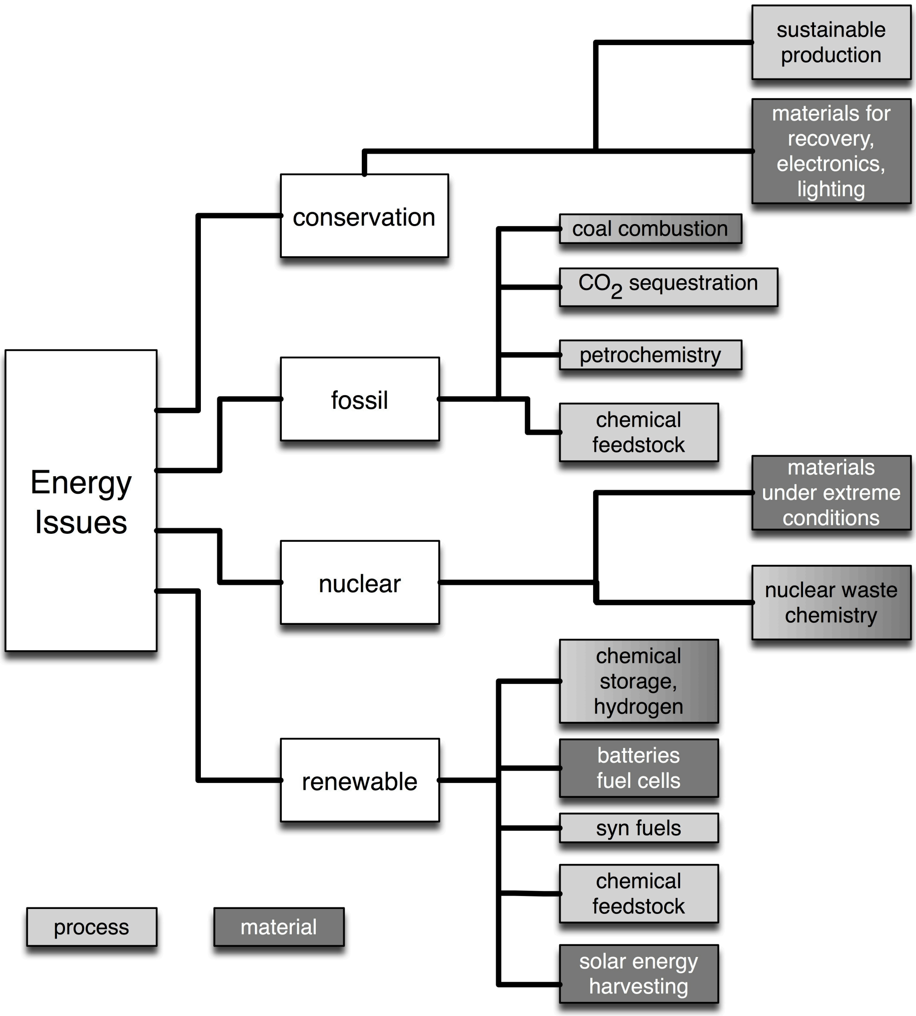

Figure 30.1: EnerChem designates the multiple contributions of chemistry to the energy challenge. The shading indicates the main contribution from material (dark grey) and process (light grey) developments.

Delivering the results required to address the energy challenge requires close collaboration among all conventional disciplines of the synthetic, physical and engineering branches of chemical sciences. The energy challenge is a strong motivation to further overcome traditional disciplinary boundaries and to consider chemistry not as a science auxiliary to applications, but as a broad-based discipline that creates materials and processes within its own paradigm based upon the molecular understanding of transformation processes of matter. This perception is expressed in the term "EnerChem," which designates the interdisciplinary contribution to the energy challenge by chemistry, working together with the biological sciences to develop biomass-based energy conversion approaches, and with the physical/ engineering sciences on electrical and mechanical energy conversion systems.[10]

The following text concentrates on the contributions of EnerChem to the challenge of integrating regenerative energy into supply chains of energy. Within this segment, the contributions of chemistry to the development of solar cells and to materials for windmills producing primary electricity are not considered. Neither are the multiple applications of improved materials and processes to saving energy by reduced consumption and through better utilization of fossil fuels considered here, despite their enormous importance. The applied solution strategies are firmly embedded in existing process chains and technologies. The reader is reminded that non-chemical issues of energy savings remain beyond the scope of this chapter.

30.5 Energy Scenarios

In the literature, several applications of energy scenarios are discussed[11] that describe economic or climatic consequences of regional developments. These scenarios assume different types of pressure from markets and politics and predict the consequences in macroscopic variables. The approaches document the necessity of discussing energy chemistry in systemic contexts. Non-technical factors are emphasized, with a strong emphasis on controlling the implementation and use of energy technologies. The technologies themselves appear as mere parameters in these scenarios.

In the present work, a different type of scenario is used. It is based on networks of technologies required to convert and store energy. Disregarding economic or political pressure, it describes the interaction of critical unit operations for providing energy to various non-related and non-coordinated applications (transportation, communication, production, domestic, retailing). The networks omit all physics-based components and are reduced to chemical processes. They assume the existence of grid systems for the exchange of electrical energy, for information exchange and for bulk material transport.

It is proposed to use the instrument of energy scenarios to identify research efforts leading—through the elimination of bottlenecks in the network—to a rapid impact of sustainable energy generation on the present fossil energy mix. An essential ingredient of future energy scenarios, besides sustainability (Asif and Muneer 2007), is continuity in the utilization of existing technologies wherever

[10] See http://www.enerchem.de.

[11] (Islam et al. 2004; Ghanadan and Koomey 2005; da Silva et al. 2005; Solomon et al. 2007; Cosmi et al. 2009; Shaahid and El-Amin 2009).

possible. Further, the scenarios rely on primary solar energy and minimize the usage of fossil energy carriers. The contribution of biomass is indispensable, as long as carbon-based energy storage systems and structural materials like polymers are used to close the carbon cycle. In these scenarios, the use of biomass is restricted to a minimum due to potential interference with food production (Mader et al. 2002; Muller 2009) and the unknown risks for biodiversity and ecology presented by an excessive shift to energy farming.

It is imperative to minimize greenhouse gas emissions as fast as possible in order to keep to a minimum the already unavoidable consequences of climate change (Parmesan and Yohe 2003; Parmesan 2006; Archer and Brovkin 2008). For the scientific justification of this postulate, see the reports of the Intergovernmental Panel on Climate Change (IPCC).[12] This has motivated the consideration of utilizing the "raw material" of CO_2 (Aresta and Dibenedetto 2007) as an integral part of the solar energy storage portfolio. The use of this energetically unfavorable raw material would create an additional sink for the most relevant greenhouse gas.

Realistic energy scenarios take into account that, because the ownership of fossil and non-fossil energy carriers is not identical, competition will emerge with a strong pressure retarding the phasing out of fossil energy carriers. The timescales and intensity of this competitive situation will be determined largely by socio-political factors and by the awareness of the general public. The complex aggregation of non-scientific factors cannot be discussed in this work.

30.6 One Possible Target Scenario

Figure 30.2 presents a target scenario for an energy supply system based on regenerative primary energy coming from physical solar energy harvesting systems such as photovoltaic power (PV), solar thermal power sources and wind power. In any case, the raw energy is primary electricity.

The general structure of the scenario represented in Figure 30.2 concerns the flow of primary electricity from physical solar energy conversion. Although some will be used directly, or stored in stationary and mobile batteries, the bulk of primary electricity needs to be stored by chemical conversion. This is due to the fact that bulk amounts of primary electricity cannot be matched in their temporal availability to the temporal evolution of demand, not even with the most advanced regulatory tools of the smart grid (Beccali et al. 2004; Charles 2009). With the long-term reduction of base-load fossil power stations, it will become impossible to supply electricity upon request and the grid system will become unreliable. Thus every energy scenario based on primary electricity will need a chemical bulk storage solution to become operable as a replacement or complement to fossil power. The difficulty of achieving effective chemical energy storage with present technologies is the largest single bottleneck to the widespread application of solar energy. This

[12]See (Solomon et al. 2007); see also chapter 31.

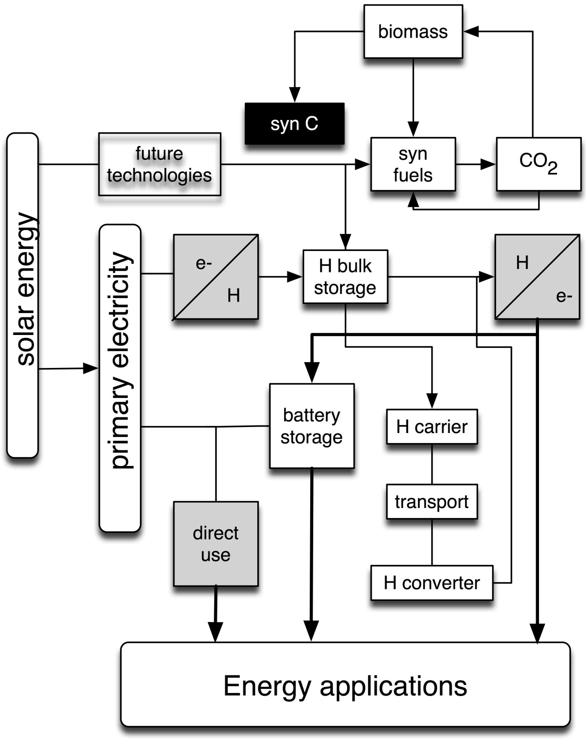

Figure 30.2: A network of energy conversion processes requiring a minimal participation of carbon-based fuels that could be operative before fossil fuels are phased out. The shaded boxes designate families of chemical processes, whereas the unshaded boxes denote processes of physical origin. The boxes marked 'syn fuels,' 'H carrier' and 'H converter' indicate primarily catalytic reactions, whereas the other boxes designate other chemical processes in which catalysis may play a role. 'Future technologies' stands for all direct photochemical processes.

justifies placing the energy storage issue at the top of the priority list for future energy scenarios.

Without effective and fast storage plus recovery systems there is no control over the temporal distribution of energy. Even with intelligent management strategies, the capacity of the electrical energy grid to regulate temporal differences between supply and demand is limited to about 15–20% of the load. With respect to the sustainability criteria, hydrogen is the suitable carrier, although other chemicals could become relevant in grid dimensions from solar-thermal processing (Fletcher 1999; Lechon et al. 2008), which is not considered here.

A great number of future energy consumers has no access to an electricity grid infrastructure. It may be debated whether the construction of grid infrastructures will be the most suitable solution (Kaundinya et al. 2009); if not, then decentralized chemical energy storage of primary electricity will be required. Suitable technologies may be not the most effective storage systems, but they must operate in rough environments without much supervision and without being able to rely on economy-of-scale advantages. This may require completely different solutions than scaled-down strategies of the systems indicated in the present scenarios. Developing such strategies must have a very high priority, so that alternatives will be available in time to compete with the tendency to build a grid in all of these locations. It is remarkable that in this debate (Kaundinya et al. 2009) it is not the technological possibilities, but mostly socio-economic arguments that play the decisive role.

The chemical utilization of solar energy (Milliron et al. 2004; Alstrum-Acevedo et al. 2005; Barber 2009), leading directly to energy storage molecules (the photosplitting of water or other photochemistry) which represents a huge challenge for the chemist (Archer and Bolton 1990; Osterloh 2008), is not expected to contribute to energy conversion on the grid scale within the next decades, but is considered as potential later-generation technology. This assumption is based upon the notion that it is very hard to optimize a network of photon-driven charge separation systems while simultaneously developing devices to allow the immediate use of the energy from the charge separation (as hydrogen, for instance) to be converted into chemical energy.[13] Due to conflicting property demands, this task is all the more difficult when charge-separation and energy conversion are coupled in a single device (such as a chemical water splitter or an "artificial leaf"). The fascination of the idea to combine solar energy conversion with chemical energy storage in a single-step process should not be disregarded (Barber 2009; Yagi et al. 2009), but from the present status there is still a long way to go before a sustainable and scalable process is achieved.

30.6.1 Batteries

Only a small fraction of the primary electricity from solar sources (Figure 30.2) can be used directly; a larger portion may be stored in batteries (Tarascon and Armand 2001; Wakihara 2001; Shaahid and El-Amin 2009), some of them operating in mobile applications such as cars. A substantial amount will have to be stored chemically: the day-night cycle and seasonal fluctuations require buffering on the medium and large scales, and a strategic buffer is required for large-scale and infrequent energy conversion. An intermediate form of energy storage systems is the redox-flow battery (de Leon et al. 2006), in which energy is stored in electrolyte

[13] (Bak et al. 2002; Aroutiounian et al. 2005; Ni et al. 2007; Yagi et al. 2009).

fluids; such systems are fast and can store large amounts of energy, but are of low energy density and thus suitable only for stationary applications.

Current research on batteries is largely phenomenological,[14] resulting in a multiplicity of apparently competing "design" philosophies and still incremental improvements in performance. The necessary breakthrough to increase specific storage capacities will have to rely on an in-depth understanding of the complex interface processes of the charge-carrying chemical species (Li) during discharge and charge of the battery (Breger et al. 2007; Wontcheu et al. 2008). Only few studies discuss the battery as a system of electrodes, electrolyte and membrane. As a result, the most studied process of Li metal storage is much better developed than the other equally necessary component operations of the battery. Furthermore, besides research on electrolytes, more study of the cathode is required: the need to store Li-ions and electrical charge carriers simultaneously has proved to be a bottleneck in the advancement of batteries. Many aspects of material transport through membranes, adsorption or intercalation into electrode solids and charge-exchange processes, are not yet understood on the necessary atomic level. In particular, the solid-solid reaction processes occurring during the charging and discharging of batteries (Padhi et al. 1997; Tarascon and Armand 2001; Pasero et al. 2008) constitute an area of theoretical research[15] concentrating on issues of defect dynamics, grain boundary chemistry and the reversibility of internal nanostructuring.

The design and control of these properties in functional storage materials require robust synthetic concepts and in-situ analytical tools rarely used so far (Breger et al. 2007; Agrawal et al. 2008; McBreen 2009). The augmented use of solid-state NMR has given clear insight into the complexity (Breger et al. 2007; Wontcheu et al. 2008) of the Li-ion battery system under operation. New in-situ tools are needed to provide experimental access to solid-fluid interfaces at ambient conditions. Synchrotron-based electron spectroscopy at tunable high energy and high resolution (Salmeron and Schlögl 2008) can offer such information.[16] Scalable synthetic concepts based upon composite materials such as nanostructured carbon systems (Zhang et al. 2008; Hu et al. 2008, 2009) will be carried further and extended to other functions, as chemists aspire to replace electrode materials such as Ru oxide, which are expensive or unavailable in bulk (Armand et al. 1985; Music et al. 2002). Progress in this area depends on the capacity to handle the complexity of solid-liquid and solid-solid interfaces without present-day oversimplifications that prevent the simple translation of existing fundamental knowledge into functional systems.

Combining solid-state chemistry with electrochemistry (Jamnik and Maier 2003) is critical for the entire energy issue and has far-reaching implications for

[14] (Gao and Dahn 1996; Padhi et al. 1997; Croce et al. 1998; Tarascon and Armand 2001; Wakihara 2001; Shaahid and El-Amin 2009).
[15] (Arico et al. 2005; Balaya 2008; Manthiram et al. 2008; Hu et al. 2009).
[16] (Chan et al. 2006; Knop-Gericke et al. 2009; McBreen 2009; Mori et al. 2009).

many aspects of the energy challenge such as fuel cells and water electrolysis. The operation of all solid-state storage systems for thermal energy (Kalogirou 2004; Steinfeld 2005) or hydrogen (Schlapbach and Zuttel 2001; Nath and Das 2007; Wang and Yang 2008) depends crucially on defect engineering and on nanostructuring in order to allow reversible diffusion processes to occur with constant kinetics. Electrochemistry would serve as diagnostic tool in these systems. The interdisciplinary nature of such research is realized (Gooch 2000) but rarely approached,[17] as substantial disciplinary boundaries between experimentalists and theorists in both fields hamper rapid progress.

30.6.2 Hydrogen

An intermediate chemical energy carrier is hydrogen,[18] which may be used in energy conversion plants either as a direct buffer molecule or as a precursor to other chemical systems intended for longer-term storage or bulk transportation. In the scenario of Figure 30.2, hydrogen is the central storage form. In contrast to the common perception of a "hydrogen economy" (Barreto et al. 2003; Muradov and Veziroglu 2008; Woodhouse and Parkinson 2009), here it is assumed that hydrogen will not become an energy carrier for the end user but rather be applied in processes concerning energy storage in the background of the electricity grid. This use of hydrogen has no adverse effects on the climate and avoids the downsides of insufficient energy density, and of potential dangers in handling and storage under mobile applications. Mobile energy applications may be operated through batteries, as indicated in Figure 30.2, or, if necessary, using synthetic fuels (see below).

Hydrogen generation from water electrolysis[19] is a fundamental challenge to electrochemistry and material science. Neither the present efficiency nor the applied electrode materials render present technologies scalable to grid dimensions. As this challenge has been addressed for quite some time, it is expected that massive progress in understanding the underlying interfacial processes (Bockris and Potter 1952; Conway and Bockris 1957) and the tailoring of surface electronic structures (Heller 1981) of non-noble metals used in electrodes (Martin et al. 1996; Jaramillo et al. 2007) will be necessary for any scenario utilizing primary solar energy. Substantial help for designing and understanding the relevant experiments (Rossmeisl et al. 2007; Salem 2008) comes from theory. Reaction mechanisms and derived descriptors for the prediction of the most relevant surface properties of electrode materials are being developed, allowing the conclusion that new compositions besides the conventional noble metals focusing on Ru and Pt can be found for applications to split water (Rossmeisl et al. 2007). The discovery of

[17] (Arico et al. 2005; Balaya 2008; Manthiram et al. 2008; Hu et al. 2009).
[18] (Fischer 1986; Bak et al. 2002; Nath and Das 2007; Muradov and Veziroglu 2008; Tributsch 2008; Barber 2009).
[19] (Kanan and Nocera 2008; Tributsch 2008; Clarke et al. 2009; Kanan et al. 2009).

the Co-phosphate system (Kanan and Nocera 2008) is a promising step in this direction.

The combination of water electrolysis and primary electricity generation from PV (Clarke et al. 2009) or from wind has been studied quantitatively and reveals clearly that a combination of electrolysis with hydrogen storage is a technologically and scalable option far superior to other forms of electricity storage in terms of efficiency and storage capacity. The study using a PV array (Clarke et al. 2009) further demonstrated that such technologies can operate well in a stand-alone mode and would not require a grid system to back them up.

Hydrogen is not a perfect energy carrier when it comes to mobile applications, which may be better served with a combination of mobile batteries and stationary electricity storage. Hydrogen is particularly unsafe for energy transfer over long distances. The transformation of hydrogen into a safe transport form is thus desirable for bulk energy transport. Ammonia is a transport form of hydrogen[20] that does not contribute to the carbon footprint of energy supply (Klerke et al. 2008; Kothari et al. 2008). It can be manufactured with practically no energy loss, and a transport infrastructure for grid-relevant dimensions of ammonia already exists to meet the world's demand for fertilizer. The ammonia-splitting reaction is less-well developed and requires a fundamentally different catalyst (Hellman et al. 2006) than the one used for the forward synthesis (Ertl and Freund 1999) reaction. Multiple efforts in this direction show promising results, suggesting that an ammonia-exchange energy chain (Lovegrove 1996; Schlögl 2003; Klerke et al. 2008) is quite feasible. The frequent concerns expressed about the possible use of ammonia as an energy storage system address its toxicity and smell as well as its potent greenhouse effect, which entail severe constraints on leakage. Most of these concerns arise from a biased comparison of energy carrier systems: were the existing petrochemical energy carrier systems to be evaluated on the basis of the same criteria of handling safety, odor and toxicity, and were the decades of development towards optimized handling systems considered, then little difference in risk potentials would remain. The concerns are all valid to a certain extent, but many measures can be taken to minimize the risks. This is evident in the existing global system of trading ammonia, which operates on a large scale without any major accident. The scant attention that ammonia is receiving as a potent energy storage system (not for end-use applications, but as a medium to long-term trading and storage form) is caused by a strong influx of non-scientific arguments, resulting in the premature exclusion of a potential solution with low barriers to large-scale application.

[20] (Lovegrove 1996; Schlögl 2003; Christensen et al. 2005; Sorensen et al. 2005; Christensen et al. 2006).

30.6.3 Carbon Dioxide

Alternative forms for hydrogen transport are methane or methanol (Olah 2005; Olah et al. 2009), which could be generated in dry sunny areas from CO_2 and solar hydrogen in a bi-directional gas transport operation yielding the valuable by-product water. Here, substantial efforts in catalyst development and process design are still necessary (Xu and Moulijn 1996; Aresta and Dibenedetto 2007) to reach grid-scale molecular conversions with acceptable energy losses (compared to those we face in the present energy supply system). CO_2 may be considered as the raw material for a variety of uses, as shown in Figure 30.3.

There are multiple uses of the greenhouse gas wherever abundant solar hydrogen allows the chemical transformation of CO_2, or biological processes can harvest CO_2 and the resulting biomass can be fermented or chemically refined. However, all of these uses are energetically unfavorable and require excessive solar energy to compensate for this inefficiency. Figure 30.4 presents some thermodynamic data. It is clear that CO_2 is a stable molecule, such that its activation through reductive transformations requires substantial energy, generated mainly by the formation of water or of a larger oxidized hydrocarbon. It is interesting to see that the coordination of water or of an additional oxygen atom significantly lowers the energy needed, disproving the argument that CO_2 is the "most stable molecule" and should not be used for further chemistry. These data also constitute the basis for understanding that aqueous solutions of CO_2 are still reactive with respect to corrosion or mineralization, a fact that is most relevant for the underground dumping in CCS technology. CO_2 is a useful raw material on a large scale, especially when the inevitable high-energy byproduct water is of additional value. It should be added that the collection and purification of CO_2 presents a significant and energy-consuming "detail" often ignored in the energy discussion. Otherwise, the sequestration of CO_2 alone may be achieved more effectively by biological collection and chemical transformation into solid carbon, as described in Figure 30.3 and below.

The key purpose of CO_2 chemistry is to remove large quantities of the greenhouse gas. This must be done without creating immediate or long-term dangers from the high-density storage of this gas, which is toxic in concentrated form. In Figures 30.2 and 30.3, its use is indicated in a cycle of converting solar hydrogen to synthetic fuel. This cycle may be seen as a chemical alternative to photosynthesis, yielding hydrocarbons instead of the oxygenated molecules like carbohydrates resulting from the biological process. The energy density of the resulting products from such a chemical process chain is high. The efficiency per photon of solar energy may be low, but could be substantially higher if existing biological systems were used to generate synthetic fuel (e.g., by growing corn and fermentation to alcohol, followed by acid-base chemistry to yield hydrocarbons). If solar hydrogen is combined with solar thermal process energy (Steinfeld 2005), quite substantial efficiencies can be expected.

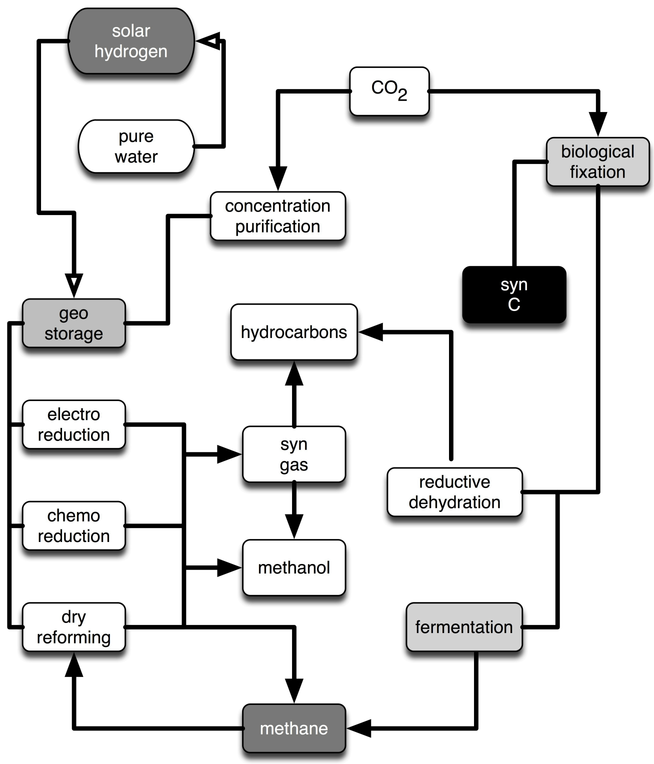

Figure 30.3: Uses of CO_2 as a raw material. Solar hydrogen is required in all conversion processes, including biological fixation. The boxes marked 'electro reduction,' 'chemo reduction,' 'dry reforming,' 'syn gas' and 'reductive dehydration' denote catalytic processes, the boxes 'fermentation' and 'biological fixation' stand for biological transformations. Methane is an intermediate product and energy carrier; the boxes 'hydrocarbons' and 'methanol' denote products for the chemical industry.

The catalytic technologies necessary to reduce CO_2[21] are not ready for application in large-scale processes. There is a good understanding of the basic chemistry of the molecule and its activation by coordination to active metal sites (Leitner 1996). The creation of either homogeneous or heterogeneous catalytic processes with acceptable energy parameters has yet to be achieved. A benefi-

[21](Nakamura et al. 2003; Sloczynski et al. 2004; Yang et al. 2006; Liu et al. 2007; Raudaskoski et al. 2009; Tang et al. 2009).

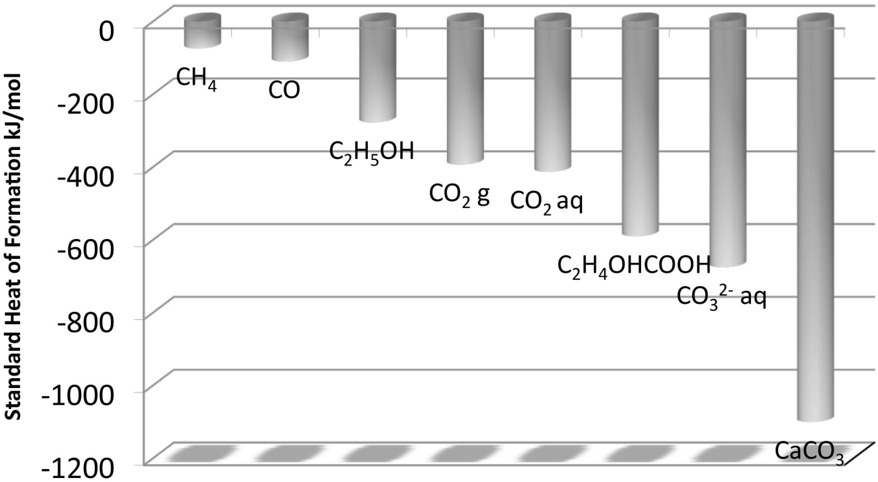

Figure 30.4: Heat of formation data for some species related to CO_2. The data was taken from (Aresta and Dibenedetto 2007).

cial boundary condition of such a process should be its stand-alone technology, i.e., its operation without having to link the process to other chemical syntheses. This design is a pre-requisite for scalability in decentralized units attached to the points of CO_2 creation, avoiding further losses by transportation of this already energetically unfavorable process.

The reverse conversion process of hydrogen generation is the oxidation of hydrogen to water leading to electrical energy. This can be done rather conventionally by combustion in motors or turbines, or by fuel cell technologies.[22] The resulting clean water is an additional valuable product in areas of the world where energy is used to generate drinking or irrigation water. The underlying chemical issues of the catalytic oxidation of hydrogen have been studied for a long time (Conway and Bockris 1957; Fisher et al. 1982; Volkening et al. 1999) and have yielded many technologically viable solutions. One of the greatest problems is the need to use noble metals, presenting the same problem as water electrolysis. It can be expected that the material issues will be solved for both processes in combination. There are additional challenges associated with high-temperature combustion, requiring catalysts to avoid nitrogen oxidation and special materials for the mobile parts of turbines in high-temperature zones. The general advancement of combustion science (Law and Kwon 2004) suggests that these issues do not

[22](Minh 1993; Singhal 2000; Steele and Heinzel 2001; Haile 2003).

represent as critical a bottleneck as the storage of primary electricity in chemical bonds.

A certain fraction of applications that require high energy density, such as planes, trucks and ships, will need synthetic fuels based on hydrocarbons. Using solar hydrogen and biological carbon sources, several process chains involving catalytic conversions that provide high quality synthetic fuels are feasible. The inclusion of biomass collection (McKendry 2002a,b; Islam et al. 2004) balances the carbon dioxide emissions: alternatively, carbon dioxide, if collected at the source, can be hydrogenated with solar hydrogen (Damen et al. 2006) as a sequestration measure. In such a way, a sink for already emitted carbon can be constructed, and a bypass provided for the continuous emission of man-made CO_2 to the natural deposition of carbon dioxide. All steps of the chemical transformations and the plant biology for the harvesting organisms need to be optimized substantially over existing technologies. Besides the challenging problem of CO_2 hydrogenation on the global scale (Xu and Moulijn 1996; Aresta and Dibenedetto 2007), the coupling of efficient plant biology to an effective chemical work-up of the biomass and the chemo-catalytic transformations require combined and concerted development.

This process chain is probably not suitable[23] to generate the bulk of transportation energy as biofuel. Neither should it be pursued as such a large-scale option, since the CO_2 involved has such a long atmospheric lifetime that a sustainable reduction of the atmospheric CO_2 level (Montenegro et al. 2007; Archer and Brovkin 2008) to early industrial times would hardly be possible. A combination of physical solar energy conversion and chemical energy storage systems involving no carbon emission will be required for the largest single energy utilization in transportation. Solar electricity (wind, PV) with hydrogen bulk storage (or redox flow batteries) coupled with battery-powered vehicles (hybrids for heavy load) may satisfy the needs of many transportation applications.

30.6.4 Synthetic Fuels

Synthetic transportation fuels for applications that require high energy density can be generated chemically by a variety of methods, all of which are known in principle and are or have been operated on industrial scales. Figure 30.5 summarizes some options. Synthetic fuels are storage forms of solar hydrogen. The carbon part can come from fossil sources, from biomass or from CO_2 as indicated in Figures 30.2 and 30.3. This part of the energy scenario is to a large extent proven chemical technology and a large body of knowledge exists on these transformations. All steps can still do with improvements in catalysts and processes, but none of them will represent a bottleneck in the energy supply system. An interesting area of research deals with the direct valorization of methane to olefins or synthetic fuels. Despite a concerted scientific effort (Fierro 1993), the results are still unsatisfactory: the energetic difference of methane from all its possible

[23](Cheng et al. 2006; Nath and Das 2007; Smeets et al. 2007; Muller 2009).

desired products requires the difficult combination of a tailored catalyst for activation and a dedicated reactor/ process to preserve the desired products from post-synthetic combustion.

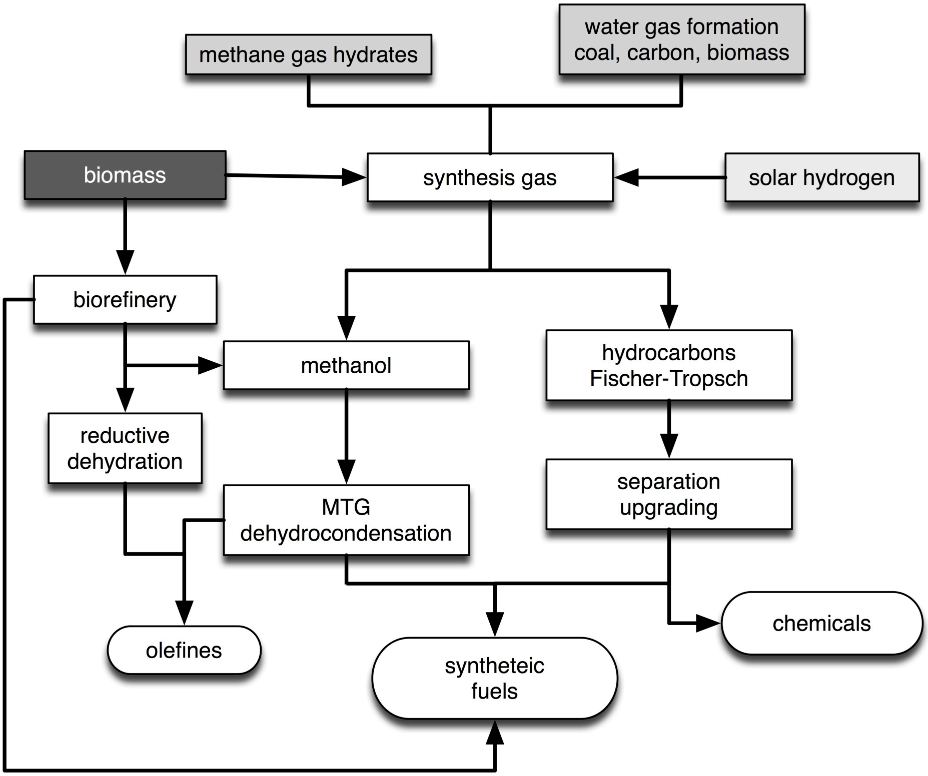

Figure 30.5: Synthetic fuels can be generated by a wide variety of processes. Solar hydrogen is required and synthetic fuels are thus a storage form of hydrogen. The carbon part can be taken from fossil sources or from CO_2 as shown in Figure 30.2.

Biological fixation of CO_2 offers the attractive option of depositing carbon dioxide as inorganic carbon after harvesting through biomass. In this way, a sink for CO_2 emissions is created, which can be operated such that no extra energy besides that stored in the biomass is utilized to generate "synC." This product is a largely aliphatic carbon polymer with a substantial oxygen content (Titirici et al. 2007, 2008; Paraknowitsch et al. 2009). Its structure is fundamentally different from that of coal[24] The material is thus not suitable as a novel fossil energy carrier

[24](Marsh et al. 1986; Haenel 1992; Gorbaty 1994; Van Heek 2000).

substitute (Longwell et al. 1995; Van Heek 2000), termed "artificial coal" or "accelerated coal." It may be used to regenerate the soil losses from carbon (Mader et al. 2002; Lal 2004) and thus help enhance agricultural productivity. Additional non-energy uses of this carbon feedstock are conceivable (Haenel 1992; Song and Schobert 1996; Schobert and Song 2002), but much additional work will be required to tailor the structure according to potential uses. A novel field for carbon chemistry may emerge, following in the long tradition of coal chemistry (Marsh et al. 1986; Haenel 1992; Gorbaty 1994), and exploiting the tremendous progress in our analytical and mechanistic understanding of carbon-based polymeric structures. In any case, large quantities of carbon can be stored safely as a solid (Lal 2004; Li and Tang 2006), avoiding the multiple unknown risks of direct CO_2 underground sequestration (Damen et al. 2006; Ketzer et al. 2009; de Best-Waldhober et al. 2009). In addition, the biological fixation of CO_2 uses solar energy directly to solve the separation and purification issues without requiring engineering solutions and their energy costs. However, the process is sustainable only if the inner energy content of the biomass is sufficient for the structural transformation, and if all non-carbon components (fertilizers, minerals) are isolated and redistributed into the biological cycle.

30.7 Technical Summary

The transition from fossil to solar energy is impossible without the ability to store primary energy in chemical carriers. Only then can the erratic, seasonal and geographic disparities be matched with the demand structure for energy. This requirement is independent from the existence of an energy distribution grid, but may require different solutions for grid-based and stand-alone energy supply structures.

Chemistry is a strategic science for solving the energy challenge. By way of process design, it provides central elements of sustainable energy supply chains (Asif and Muneer 2007; Deshmukh and Deshmukh 2008) based on the physical separation of charge carriers driven by solar radiation. In all of these processes, as well as in the necessary intensification of fossil energy utilization, which was not discussed here, chemistry will have to provide tailored structural and functional materials. The controlled synthesis of materials (with controlled and reproducible property profiles) rather than "samples" is another central task for chemistry in the energy challenge. EnerChem is chemistry's contribution to energy science and designates a multidisciplinary, long-term approach that integrates synthetic, analytical and engineering capabilities throughout the entire field, ranging from theoretical and physical chemistry over inorganic and organometallic to organic and biological disciplines. The provision of sustainable energy on the global scale is a major, long-term and international challenge. It cannot be solved in the foreseeable future by, for example, a single funding program. An educational effort to train chemists in this interdisciplinary sense will be essential to enable the engineering disciplines creating the system networks to develop creative and scalable solutions. Among scholars, an awareness of the diverse research needs within the energy challenge is also essential; the penetration of energy aspects into personal research agendas can be substantially improved.

The effective conversion of the simplest molecules like methane, water and carbon dioxide presents an enormous challenge to chemistry. Mastering these reactions will be the pre-requisite for all renewable and sustainable energy supply strategies. Nature was also confronted with this difficulty, and soon resorted to the photosynthesis (Barber 2009) of more complex molecules that can be more easily stored and handled. The benefit of this was the enormous complexity in functional materials and processes, with the overall result of low energy densities. Fossil fuels are so attractive largely due to their complexity, resulting from denaturation processes that take place during their geochemical transformation, and beneficially providing for simple energy transformations at high-energy densities.

The three disciplinary sub-forms of heterogeneous, homogeneous and biological catalysis bear a pivotal responsibility in solving the challenge of converting small molecules. Clearly, the present efforts in "energy catalysis" are still insufficient. The frequent discussion of potential energy conversion processes in terms of the technological hurdles of "inefficiency" should not be conducted in the conventional phenomenological manner, by recurring to qualitative concepts. A fundamental approach is needed, respecting the unity of catalysts and reactant as a system with multiple feedback relations in between (Norskov et al. 2002), which could be derived using the examples of converting energy storage molecules. From there, breakthroughs in improving the present technology levels can be expected.

Chemical energy research must expand as broadly as possible in order to capture many possible solutions. The research strategy may be structured in the long-term "discovery searches" discussed elsewhere,[25] and in activities driven by the shorter-term intention to facilitate the transition from pure fossil into a fossil-plus-renewable energy process chain. In order to identify the most pressing research needs, it is proposed to use the tool of energy scenarios as networks of energy conversion processes and to analyze these networks with respect to critical bottlenecks in knowledge and technology, as elaborated in the text. The scenario discussed highlights the necessity to think of energy supply systems in terms of systems rather than as isolated challenges. The processes discussed in the text are likely to be important, but clearly serve as examples rather than solid predictions of the future of the energy system. The science-based approach contrasts with the suggestion to structure energy research according to economic and societal needs (Voorspools 2004).

Converting primary electricity into chemical energy and storing renewable energy in chemical bonds (Lewis 2006) is the most effective storage strategy. This approach includes energy storage in molecules and in batteries. The present

[25] (Claassen et al. 1999; Lewis 2006; Ni et al. 2007; Muradov and Veziroglu 2008; Turner et al. 2008).

work suggests adding to the ingenuity of the chemist two sets of boundary conditions: First, existing infrastructure and technologies, as well as existing knowledge, should be used as much as possible. This requires networks of processes with a maximum number of known elements and a small number of critical bottlenecks. Major technological implementations may then be possible within relatively short timescales of decades. The second boundary condition is to absolutely minimize the utilization of rare compounds like noble metals in global applications. This requires substantial theoretical and experimental material science efforts in addition to the demanding process design.

The immediacy and urgency for finding a large-scale solution makes it tempting to prioritize the various concepts. However, it seems inappropriate to favor or disfavor any of these strategies at present, while we have still insufficient insight into the structure of future energy supply networks. The scientific exploration of all of the concepts must have priority before decisions can be taken outside the scientific community in favor of or against any of these concepts.

As there will always be the need for non-electrical energy, it is further useful to study direct chemical solar energy harvesting through high-temperature processes and solar-thermochemistry (Fletcher 1999; Kalogirou 2004). These processes and their chemical implications are not covered here. Solar-thermal power generation requires energy absorbers with unprecedented functional properties. Solar-chemical processes present major challenges to solid-state chemistry, as ways must be found to control the kinetic issues of solid-gas transformations.

The present approach stands in some contrast to the more radical suggestion of using chemistry to build an artificial photosynthesis device[26] as a single-step (Lewis 2006) process. This most challenging approach may be an element in later-generation energy supply networks (Grubler et al. 1999). The enormous hurdles to developing, optimizing and implementing such a device into a world-scale technology may take more time than we have at our disposal to begin with the transition to stable, renewable energy scenarios characterized by a controlled availability of energy. To this end, the storage of solar energy in chemical bonds is the common strategy, but a modular rather than an integrated approach is suggested here. The integrated generation of chemical storage molecules can be accommodated without difficulty into the scenario presented in Figure 30.2. Their development is not a rival but a valuable addition to the process portfolio. It should further be recognized that economical factors may not support a rapid, disruptive technology change based on an entirely new process.

The use of hydrogen has been the subject of multiple and controversial discussions in the past (Barreto et al. 2003; Muradov and Veziroglu 2008). Acknowledging the arguments and taking into account the critical need to reduce our carbon footprint, we suggest using hydrogen as a universal energy storage molecule as soon as possible. This does not imply using small mobile hydrogen storage devices

[26] (Gratzel 1981; Meyer 1989; Milliron et al. 2004; Alstrum-Acevedo et al. 2005; Kanan and Nocera 2008; Barber 2009; Yagi et al. 2009).

(Schlapbach and Zuttel 2001), but rather buffering the grid against fluctuations using stationary installations (Christie et al. 2000). Transportation energy, a key target of the concept of a "hydrogen economy" (Barreto et al. 2003), can be supplied to a large extent from electric traction, with batteries being charged partly from primary electricity and partly from the stored energy. With respect to reducing carbon emissions, it is essential to minimize the use of carbon-based chemical storage systems to buffer short-term fluctuations in solar energy supply systems. Frequent use of the stored energy would mean a further large contribution to greenhouse gas emissions. Solar hydrogen is further needed in large quantities to provide chemical alternatives to geological CO_2 storage. Such alternatives also provide clean water and synthetic fuels.

It may be concluded that the task of transforming primary electrical energy into hydrogen is the single most pressing bottleneck faced by the sustainable use of regenerative energy. The fundamental scientific challenge is to control the kinetics of oxygen redox chemistry. Oxygen evolution and oxygen reduction are critical steps in all energy harvesting and transformation systems. This results from the fact that 4 redox equivalents are needed to reduce or oxidize one di-oxygen molecule. A whole sequence of elementary steps dealing with highly energetic and reactive intermediates of oxygen (peroxides, radicals) needs to be managed, such that only minimal damage of the reaction center takes place during the complete turnover. Besides reactions to split water, fuel cell reactions and even transformations of biomass into less-oxygenated hydrocarbons are additional examples that call for the improved control of oxygen reactivity.

Largely carbon-free energy storage is a medium-to-long-term target; intermediate scenarios using methane, methanol or ammonia or any combination of these carriers as storage forms may be implemented as a transitional solution. Carbon dioxide sequestration measures taken to compensate for emissions, even when they are energetically unfavorable, must be introduced in parallel to such large-scale storage. It is strongly suggested that sustainable and safe chemical transformation strategies be designed and implemented, and that underground storage be used minimally. This should serve only as a temporary measure, with the clear goal of recovering CO_2 later for safe disposal. The enthusiasm about geological sequestration as a permanent measure[27] is not shared by this author, as no evidence for the permanent safety of such a large-scale experiment can be given if the CO_2 is deposited underground in a non-recoverable, and non-mineralized form.

Biomass-based technologies have potential for the sequestration process. In addition to carbon mineralization, a possible auxiliary role for biomass through synthetic fuels is seen for transportation energy, along with the atomic-efficient use of biomass as a feedstock for the chemical industry, which requires about 3% of all primary energy supply. Transformation of biomass into the required olefins is thus an important step toward decoupling the continuing needs of the chemical industry for hydrocarbon feedstock from the present fossil sources.

[27] (Zwart and Boerrigter 2005; Li and Tang 2006; Friedmann 2007; LeNeveu 2008).

30.8 Global Aspects of Chemistry for Energy

The discussion so far has clearly shown that there is an option to meet the energy challenge with regenerative energy harvesting techniques, coupled with as yet non-existent storage technologies and using the existing infrastructure for electricity. There is no fundamental need to invoke novel, non-existent technologies like nuclear fusion with magnetic or fast reaction concepts. We can and must effectively utilize highly concentrated electrical and process energy if these nuclear technologies are to succeed. In view of the potential of regenerative energy, and considering the socio-political consequences of the emergence of yet another oligopoly of nations controlling such high-end technologies, it is assumed that regenerative energy supply will always play an important role in long-term scenarios. It has also been discussed that the timescale for the transition from fossil-based to fossil-supported and then fossil-free energy scenarios is decades rather than years. With these prospects, it is appropriate to discuss the status of chemistry as the science discipline enabling this transformation. Both processes and materials will be critically needed for the generation, storage and distribution of regenerative energy. We note that the structures of physical sciences and of life science are substantially different from that of chemistry. It is thus difficult to investigate the state of an "energy science" which does not yet exist as discipline in science with respect to its structure and dependence on external factors in a global context. Neither is it necessary to discuss the general global character of the sciences as forerunners of economic globalization, as discussed in this volume.

The technical summary presented above serves as a basis for identifying the needs and challenges of regenerative energy research to the extent that chemistry is involved. In more general discourses on the subject, it is clearly accepted that the necessary knowledge forming the basis of technologies either already exists or can be generated without much effort and many resources. It must be emphasized that this is not correct. The preceding text shows clearly that the most fundamental and basic questions of chemistry are at center stage of the energy challenge. More than a century of fundamental and applied chemical science have not been sufficient to solve these issues, to an extent that the existing answers are anything more than a basis for designing research strategies as illustrated above.

This surprising knowledge gap is due in part to lacking technology demands, and in part to the present socio-economic system's inertia in responding to the challenge. The global nature of this system, outlined in several contributions to this volume, creates the global dimension of the energy challenge. It is stated here that the availability of sufficient energy in suitable forms is the foundation for all of man's sociocultural activities and thus a strategic enabling condition of human existence, requiring the utmost attention of those responsible for the progressing development of mankind.

The following section will elaborate on some factors affecting the necessary rapid adaptation and change in our energy supply scenario. These factors are illustrated from the point of view of a scientist. We identify factors inherent in science and other factors from outside the field that represent boundary conditions of energy research. The term "science" is understood here as describing a global scientific community of researchers active in energy research and more closely in EnerChem. It is no limiting factor that these scientists are distributed over many countries, as chemical science is fully globalized in the sense that no cultural barriers to cooperation among scientists exist. Many institutional barriers do exist, however, some of which will be discussed below.

The origin of the internationalism of chemistry goes back to the symbiotic relation between chemical science and the chemical industry. This unique relation between theory and practice, which does not exist, for example, between physics and industry, was and still is a key driver in the evolution of the chemical industry as a strategic but rarely seen enabler of all technologies; the chemical industry provides the material solutions to most modern industries. The global character of the chemical industry in turn created a global network of academic relations, forming the basis of a global science. The excellent scholarly organization of chemistry, and today's successful collaboration among many learned societies creating international networks of dissemination of chemical knowledge, have built a strong foundation for global scientific activities. This network has responded sensitively to the challenge of energy science in a plethora of conferences and new publication channels such as books and journals. It began to incorporate energy issues in teaching and international student exchange programs. It initiated the creation of many national programs for funding research. The intensive evaluation process controlling every activity of a chemist is a further strong impetus toward internationalism, as international review is a common practice for projects, research programs and even individual research papers.

30.9 Limiting Factors Within the Science

Under these excellent internationalist conditions, the energy challenge should be in good hands, with chemistry expected to provide strategic contributions. A non-exhaustive description of these solutions was given in the technical section of this chapter. Even for this set of answers, it becomes apparent that substantial interdisciplinarity (between inorganic, physical and organic chemistry, biology, physics and engineering sciences) and strong collaboration will be essential. Most researchers share this view, but there is a set of serious shortcomings preventing the desired rapid and deep impact of chemical science on technology needs. Many of them are of global character in the sense that they are present in many national communities. The close cooperation of individuals leads to de-facto standards of practice. This causes strong trends toward mainstreaming paradigms, and fails to support local attempts to overcome deficiencies. In this way, the normative power of global cooperation is auto-inhibiting adaptive trends toward optimizing internal and external scientific practices.

30.9.1 Lack of Awareness

Chemistry traditionally has been directed towards the synthesis of novel compounds and materials. That the functional analysis of chemical processes is being equally important for the directed synthesis of material solutions in energy science is less well accepted as an area of chemical research. The response of chemistry to energy is thus to a large extent a synthetic approach of providing new molecules and solids to be used in energy applications. This is misunderstood, but unfortunately sometimes practiced as the "repackaging" of familiar research activities. The notion that the energy challenge requires a functional understanding of basic chemical reactions not yet under the control of chemistry as exemplified in the technical section (e.g., splitting water or activating CO_2) is not well communicated. This is particularly true for an understanding of these processes beyond deciphering the biological mode of operation. A popular view that copying biological processes would automatically lead to effective and structurally simplified processes has proved to be incorrect. The history of the ammonia synthesis process (Schlögl 2003) delivers an excellent example for this conceptual fallacy.

Another aspect of lacking awareness is the sheer dimension of the energy challenge, also outlined in the technical section of this chapter. Intelligent and elegant synthetic pathways to energy chemicals such as hydrogen are of little use if they cannot be executed in global dimensions. A typical example of this dilemma is the splitting of water directly into the elements performed in nature by photosynthesis (Gratzel 1981; Barber 2009). A tremendous effort is undertaken to copy or mimic this reaction that is not particularly effective in nature. Given that we have many more degrees of freedom for choosing reaction conditions than nature did, we may consider other solution strategies. Despite the well-known fact that the extremely complex biochemical process of photosynthesis has an overall efficiency of about 0.5%, synthetic chemists have gone to great lengths to copy it. From a theoretical point of view, understanding the details of biological water splitting holds important answers for the design of artificial systems as well, but it should be made more clear that re-engineering biological processes is a very demanding objective which chemistry has not often succeeded in achieving.

Many energy conversion reactions use noble metals (Pt, Ru) or other rare components such as nanoparticles with organic modifiers. As outlined above, sustainability clearly precludes building an energy solution upon a resource that is insufficiently abundant. On the scale of energy applications, many material resources are rare, limiting the choices of chemistry. This holds not only for absolute abundance, but also for the life cycle of these materials: if nanoparticles degrade rapidly under operating conditions, it makes no sense to suggest their use under considerations of energy efficiency and waste minimization. This aspect of global chemistry, dealing with mineral resources and their mining or recycling, is not a popular research topic. It must be noted, however, that industrial chemists are well aware of such issues and are trained to look for resource diversity and feedstock changes. An interesting gap between the perceptions of academic and industrial chemistry can be noted here, having to do with the dislike of many academics for "applied" aspects of their work.

30.9.2 Lack of Sustainability

In energy research, sustainability has to address both the solutions and the research effort. All chemical energy conversion processes are complex sequences of individual reactions, which must be carried out at separate spaces and times to qualify as an energy storage solution. The creation and optimization of chemical process flows is a long-term challenge that will require multiple design iterations. Many projects in energy chemistry ignore this critical need and try to solve an isolated problem without considering the systemic effects.

Energy research is not sustainable unless it follows an initial idea, via laboratory feasibility studies, to a level of execution at which life-cycle considerations can assess the idea's usefulness on a larger scale. What is at stake here is the complex issue of the interface between science and technology as a strong barrier to diffusing scientific solutions into technological realizations. One consequence of globalization is that many theoretical scientists become aware of this barrier and, in some communities, actively surmount it by supporting small companies.

The evolution of new dimensions of synthetic chemistry, to allow the modification of supra-molecular properties of materials in a much better way than is presently possible (Schreiner 2003), is another aspect of sustainability. Within the synthetic ingenuity of chemistry, we still are confined to synthesizing objects of low hierarchy, as it is difficult to control the aggregation of molecular objects to the complex, non-translational packing so frequent in natural systems (enzymes), and so desirable for energy conversion. Chemistry must refocus more broadly on its own methodical evolution (Grimsdale and Mullen 2005) than on its enabling function for many other sciences (life science, material science). The short-lived character of many funded project initiatives precludes the necessary long-term efforts. In this respect, the globalization of science, with its strong trend towards harmonizing procedures and conditions of funding, is not beneficial.

A critical scientist's estimation of the extent to which a hypothetical solution to an energy problem may be sustainable is often considered "non-scientific" or "applied" and hence not highly valued. This prejudice may be of some value with respect to predictions concerning the possibilities of industry and engineering to improve the quality and efficiency of complex processes. The semiconductor or photovoltaic industries are lucid examples for the beneficial effects of global markets and global competition in driving technological evolution. However, there are multiple aspects of an energy-related reaction that can be interrogated for sustainability beyond sensible estimates of economy of scale. Many research projects might not be necessary if this argument were applied, although it is important not to discourage revolutionary novel solutions. The simplest way to safeguard against such streamlining is to perform a life-cycle analysis at a stage of maturity defined by the reproducible repetition of the intended function in a research project. The tremendous demand for speed in science, partly inflicted by global competition for rewards, is contra-productive for such measures that could help to self-protect against research efforts that must be deemed superfluous in terms of achieving an energy research objective.

30.9.3 The Role of Theoretical Science

The arguments made in the preceding section open the discourse about the role of theoretical science in the energy arena. From the view of augmenting our fundamental understanding, no project can be rejected, provided that it is conducted with the scientific rigor necessary to allow insights to be derived from it. Many involved in the energy challenge believe, however, that solutions must be imminent given the enormous amount of funding and the pressing need for solutions. This creates a strong preference all over the world for two science trends, both of which are adverse for sustainable solutions.

One trend is the belief in a phenomenological search for solutions. Besides many dead-ends, several creative and new concepts may arise from this approach. However, they do require serious and rigorous investigation after their identification. Yet the global practice is to initiate the founding of start-up companies and attempt to commercialize solutions without having the necessary scientific understanding. The other trend is that nothing follows upon an initial report of a new discovery and the science "caravan" moves on.

This practice wastes many resources in academia and in the economy. Moreover, it has the strong negative effect of discouraging whole lines of solution strategies once the first element fails to be realized commercially, or to set a research trend thanks to rapid and simple reproduction. The approach further creates a spirit of exaggerated expectations by societal forces, which is anything but justified in view of the magnitude of the energy challenge. This difficulty is an import to Europe from Anglo-American science culture. Its adverse effects will be felt only in longer-term perspectives. It should be said, however, that this culture of attempting a rapid transition from science to technology also has the positive aspect of stimulating more risk-averse communities.

It is extremely important, however, to recognize from the technical part of this chapter that the energy challenge cannot be solved by a phenomenological-engineering type of approach. What it requires is a deep fundamental research effort that revisits the basic research issues of several disciplines. The technical summary lists several examples and highlights the strategic relevance of solving these issues for the energy challenge.

The fundamental aspects of energy science and the long timescale of its operation also entail the need to develop suitable curricula to educate energy science specialists in several research fields inside and outside of chemistry.[28] This has

[28] See also chapter 25.

been realized in some engineering disciplines, but is not so common in traditional basic sciences.

30.9.4 Interdisciplinarity

The technical part of this chapter has clearly shown that a key characteristic of energy science is its interdisciplinary nature. Although generally agreed and strongly advocated by funding agencies, there are serious hurdles to practicing this interdisciplinary research. Many energy research projects consider only intra-disciplinary solution strategies. Systemic considerations or even systemic research strategies are rare. This allows faster action in the initial phases of a project, but creates serious problems in later stages of integrating knowledge to the extent that new solution strategies need to be applied. A useful example is the conversion of biomass to biofuels (Ragauskas et al. 2006), where after initial hype, the complexity of selecting useful pathways is only now becoming apparent (Kunkes et al. 2008; Clark et al. 2009). Reasons for the preferred intra-disciplinary research strategies are:

1. The lack of a suitable technical language shared by neighboring disciplines. This deficit inhibits the first contacts between scientists, creates prejudices and builds hurdles to communication.
2. The lack of basic knowledge about best practices between disciplines and the limitations to facilitating interdisciplinary discourse through the transfer of knowledge. A typical example is a lack of mathematical training hampering the concise exchange and evaluation of data.
3. The disharmony of practices by graduate and undergraduate students between disciplines as well as between countries in frequently needed international interdisciplinary collaborations. This encompasses aspects of education and training, and aspects of executing research. The much-lauded global character of science is not reflected when it comes to executing practical collaboration on a level of training below the Ph.D. Yet, at this academic level disciplinary socialization is already strong, and academics' openness for truly interdisciplinary work is decreasing. The strong push by industry to hire students at the earliest possible point in time is another obstacle to investing the extra time required to learn interdisciplinary research.
4. The dominant role of the pressure to seek immediate rewards for scientific efforts. This greatest of all obstacles prevents collaborators from finding the time to overcome the above-mentioned hurdles. Many researchers simply consider it too time-consuming to engage in serious interdisciplinary research requiring them to understand new techniques and procedures.

This incomplete list looks quite negative in light of the clear trend of global science to foster and encourage interdisciplinary research. Against this stands merely the time horizon to bring researchers of different national and disciplinary backgrounds together and let them develop the necessary common working ground beyond superficial demonstrations. Such forced interdisciplinary activity is not suitable to bring about truly new science and, due to its bureaucratic overhead, can prevent even effective disciplinary research. It should be emphasized that many positive counter examples of fruitful interdisciplinary collaborations do exist. They result from the long-term efforts of individual researchers who feel that the advantages of collaboration do surpass the adverse barriers indicated above. In Berlin, an example exists of an interdisciplinary collaboration in the field with strong multilateral global nodes in the network. It was created through the national Excellence Initiative (*Exzellenzinitiative*) as a "Cluster of Excellence" (UNICAT).

30.9.5 Scholarly Coordination

Some areas of science are traditionally well coordinated on a global basis. High-energy physics, genetics, astronomy and earth system science may serve as examples.[29] These sciences developed many of the practices enabling globalization in the economic sector long before the wider society recognized the strategic character of developments like the Internet or digital data sharing and archiving.

Science thus has the ability to globally self-organize its activities. In the energy challenge, this coordination has yet to take place. This would be most desirable in view of the great pressure put on decision makers in economy and society. The pivotal discipline of chemistry is not used to major collaborative activities and follows internal reward systems that support the individual achievements over collaborative activities. This is deeply rooted in the character of chemical science, with its concentration on synthetic efforts that today can be handled by small teams or even individuals with perfected descriptive rigor (synthesis protocols and structural analysis of the products). Chemistry that does not follow this paradigm was outsourced from the core discipline into neighboring disciplines such as physical chemistry, chemical physics, material science or chemical biology.

It is thus not expected that traditional chemistry will take the lead to better organize the research efforts in energy sciences from within the community of practitioners. It is more likely that a new community of "energy chemistry" may form from the boundary regions of disciplinary chemistry. This new community may then practice self-organization in a way that includes coordinated efforts directed toward internal projects as well as toward interaction with the external parts of the scientific community.

It is not advocated that external bodies such as funding agencies or science planners occupy this niche of organization of scientific activity. Neither is the sometimes inadequate presentation of normal scholarly discourse to the general public (as recently with the IPCC) helpful in a situation where society expects from its many scientists a constructive and serious attempt to solve this major

[29] See, for example, chapter 28.

challenge. Any moves presenting individual views or even profiling measures to the public are fatal to the aspired-to and essential self-organization of energy science.

30.10 Global External Interfaces

We assume that the ability of chemistry to deliver its critical contributions is also limited by factors outside the scientific community. These factors are not independent from the community, as there are multiple transactions across the boundary. But because decisions to moderate the adverse influences cannot come from within the community these factors are classified as external.

30.10.1 Lack of Independence

Energy science is an expensive operation requiring billions of dollars for its effective operation. There is great public support for energy science, at least within the usual five-year life cycle of standard funding. Indeed, the fact that many energy science centers have been created worldwide documents that the long-term character of the challenge has been recognized. This should give science the necessary independence to develop its strategic views and to bring about reliable solutions based upon rigorous understanding.

This ideal view is distorted by the strong influence of economic factors. Both individual researchers and funding bodies readily follow the argument that a given research idea has to be evaluated on the grounds of real or hypothetical economic feasibility against the backdrop of the present energy market. This is a dangerous evaluation criterion that blocks many useful concepts, as they appear either uneconomical or even “disruptive” in the way that they would not fit into today’s economic paradigm.

It is argued that new energy scenarios must find a connection to the present situation due to the mere magnitude of remodeling the global energy infrastructure. At least for technologies bridging to existing energy supply chains (such as solar fuels or batteries for transportation), this requires the potential to break even with current technologies. The following important points should be considered when new technologies are evaluated.

The energy economy is not a free market, but highly regulated by local and international political settings. Global enterprises, cartels of production, subsidies on energy use and the fact that no price has to be paid for producing CO_2 are strong factors that make energy prices dependent on politics rather than on non-speculative market forces. The accuracy to which an economic break-even of a technology can be judged is thus limited and may be obsolete when political boundary conditions change. The debate about the value of photovoltaic devices in Europe is a timely example for such a critical influence of “economic” considerations.

Economic factors directly influence decisions to fund energy projects. The debate about electro-mobility and required advanced battery technology strongly affects funding opportunities in inorganic chemistry and electrochemistry. The quest for biofuel from agricultural products is a massive impetus for science projects in biology and chemical engineering aspiring to "biorefineries." There is little long-term analysis behind such decisions, as useful as they may turn out to be. Science investigating the adverse effects of monocultures of energy crops on biodiversity and the stability of ecosystems finds little support, as does climate science looking into experimental verification of "CO_2 neutrality." Energy storage by chemical conversion is less popular for funding than research into smart grids and components of solar thermal power and windmills, as these are established technologies. The trend emerges that research supporting existing infrastructure and technology is much more readily funded than disruptive concepts. This represents an auto-inhibiting effect for conceptually different approaches to an energy scenario not based on traditional fossil fuels. It is advocated here that more diverse funding for science would be strongly needed to complement the large-scale programs planned for energy science approaching technological application. The bottom-up creative power needed for truly innovative concepts is strongly suppressed in science close to the product development phase. Both aspects are needed, but there should be a sensible balance between research and development.

Economic factors also affect the development of regionally adapted solutions. Global trade and the massive trend to outsource production from high-level societies into emerging economies exports not only labor but also energy supply pressures. This massive but rarely discussed consequence of globalization means that emerging countries not only have to provide for their own energy needs, but also for our energy in the form of imported products, with the effect of minimizing the latitude for seeking local, non-Western answers to the energy challenge. Decentralized distribution, unusual feedstock or unconventional transportation solutions are hardly possible with a global technology-exporting industry selling power stations, grid solutions and transportation systems based on identical concepts to all places in the world. A science-driven debate about alternatives to the first-world's energy supply and models of consumption for areas still without such infrastructure has found insufficient support.

Economic factors stabilize the existing infrastructure and thus tend to delay the market penetration of novel technologies. This argument is not inherently connected to market economics, as a far-sighted economic development would welcome the diversification of its technologies and resource streams. In many cases, we observe globally a defensive attitude of the economy against such diversifications. This may be rooted in the regional view that there is no need for diversification that causes additional costs. This is amplified by the deep global interdependence of financial institutions. This mechanism narrows the view of global players that their regional diversity may require different answers in different markets at different stages of maturity and local development. Failure to follow such a diverse trend reduces the options for science to turn results into technology and thus to prove the validity of novel concepts and materials. The global economy should exert massive pressure on science to come up with diverse solutions.

30.10.2 Dissemination and Open Access

A substantial portion of all shortcomings discussed so far can be related to communication problems. Without analyzing this important point any more deeply, it is easy to see that hurdles in dissemination of scholarly information have a fundamental effect. The many researchers in institutions and regions who are not privileged by wide access to scholarly dissemination results are simply not aware of the knowledge and communities dealing with issues critical to their work. The fact that most scholarly information is still enshrined behind the walls of commercial publishers (Velterop 2003; Antelman 2004; Armbruster 2007).[30] constitutes a high hurdle to global cooperation and exchange. This is also true, to a lesser extent, for the flow of information between academia and industry. The fact that the explosion of academic productivity makes it even more difficult to follow the important developments from outside the community creates a growing barrier to the equal dissemination of knowledge and understanding among all stakeholders of the global energy issue.

If open access cannot be realized for the global scientific community,[31] then it would be a critical enabling project to collect and sort the energy-relevant information and make this consolidated body of information available to the global community. Such an action could copy the activities of the IPCC to perform a similar, yet critical analysis for the earth system sciences.

30.10.3 Relation to Politics

The uneven distribution of information within the science community is one factor affecting the communication between science and politics. Politics has almost no independent access to scholarly information and relies on aggregation through experts and their dialogue with political actors. Politics has to decide on science sponsorship and on measures to implement the results from science. Comprehensive information for both politicians (access to primary science results at least for selected uses) and experts is key to the best possible consultation. The transformation process required to render scientific primary information useful in the political discourse is a critical yet neglected action in global energy science. The normal dispute within the science community needs to be consolidated and transmitted in the form of trend statements to the outside world. The failure to do so creates information gaps filled by non-experts spreading opinions that are dangerous and hard to refute with arguments based upon validated facts.

The history of chemical accidents in production is a vivid example of how inadequate communication can ruin the efforts of a whole science. Today, chem-

[30] See also chapters 28 and 32.
[31] (Velterop 2003; Antelman 2004; Poschl 2004; Schlögl and Velden 2005; Armbruster 2007).

istry has a bad reputation in society and politics stemming from the false image that it has denied risks and scrimped on safety measures. This reputation represents another hurdle for dialogue between science and politics. The chemical science community is not as attractive as other branches of science and thus not so present in the small budget of attention that politics tends to share with all sciences.

The complex relation of chemical sciences with politics in general has an adverse effect on the flow of information, with the consequence that incorrect views spread easily within the political debate. This does not enhance the influence of science versus economic interests when it comes to strategic decisions or the design of funding programs. These deficits are less a challenge for Anglo-Americans, with their different approach to discourse and lobbying than in Europe. In Asia, politics pays a great deal of attention to the energy challenge, and despite the strong influence of economy, science organizations also enjoy substantial influence in the debate. It can be stated that inadequate self-organization, paired with the issue of chemistry's reputation, results in a deficit in the dialogue with politics. This is less a problem for issues affecting the traditional chemical industry, where the long-standing industry-academia relations are helpful. In the more interdisciplinary part of chemical energy science, this is a more serious problem, as can be judged from the quality of many political statements on energy issues. The consequences can be critical if incorrect decisions on energy policy are taken on the basis of substantially incomplete scientific information. An example in Europe was the biofuel program, which caused multiple image disasters for the future of helpful biomass conversion concepts within and outside of the energy science community. Another example of such a process is the ongoing debate about carbon capture and storage as a measure that would make it possible to continue using fossil carbon without damaging the climate. The technical part contains a number of facts known in chemistry but not clearly understood in other sciences, yet politics has stepped forward with firm conclusions about the usefulness of this method. The observation that much is unclear and that other alternatives for carbon sequestration (albeit less commercially attractive under today's conditions) may be investigated should cause politicians to be more open to the evolution of knowledge and to strongly boost the speed at which critical knowledge gaps are closed.

30.10.4 Chemistry and Society

The demand for energy is a global issue. However, its origin and the societal context in which it is projected are local and quite diverse. Energy science will thus have to develop diverse solutions against the unifying trend exerted by the global operations of the energy industry. A global challenge requires a set of local answers.[32]

[32] See also the discussion in the survey chapters 16 and 24.

Chemistry may have to learn that these diverse needs do exist in addition to local perceptions. The local view of an individual scientist in a local society finds its reflection in controversial views on approaches and solutions within the global community. Much of this discussion is not fruitful and hinders the evolution of our understanding. It further spills out to society, where it is often abused for political debates not intended by the scientific discourse. It would be a great achievement if energy researchers would become open enough to improve contact with their local society and then reflect their experiences upon the global view of consolidated international results. These contacts should be bi-directional in the sense that both parties exchange information. Societal concerns are serious boundary conditions to science and technology as illustrated by the example of nuclear energy. Early awareness and serious analysis of such concerns, but also effective dissemination of the results of such studies through independent bodies, are obligations that science and scientists owe to their societies. This aspect also has a global dimension, as the immediacy of information dissemination may create rapid worldwide concerns over local issues that are difficult to comprehend elsewhere. An example is the speculation about the possible reduction in the area of the rain forest area for sugar cane production. In reality the two areas are thousands of miles apart from each other and would not compete. Unfortunately, in other respects of bio-renewable feedstock this competition does or did exist, calling for a differentiated view rather than for a general statement.

The energy issue demands from its researchers a substantial dose of societal reflection that goes far beyond the requirement of purely academic research. It is not only the possible consequences of individual findings that need such consideration, but research practice as a whole that requires critical reflection. The international composition of this newly emerging scientific community facilitates such reflection, as it reduces the sharp boundaries for paradigmatic modification inflicted by the traditional disciplines.

The societal context of energy science demands critical competence by the researcher to perform a rudimentary assessment of a product life cycle and of process sustainability. Both criteria are better indications for priorization of resources than the expected distance to market. The central responsibility of the energy researcher is, however, to remain driven by curiosity and rigor in practical actions. Missed opportunities are the greatest loss that society can suffer from the work of science. This is true globally, calling for moderation in the speed of the race toward academic rewards and demanding that room remains for critical consideration and interdisciplinary systemic discourse over the results.

It is superficial to analyze the behavior of science and society within a single point of view. Many activities support energy science both within the community and within society as a whole. The global operation of science greatly accelerates these activities, leading to similar thoughts and concepts. It remains the responsibility of individuals to use the positive momentum of global science and combine it with the local character of challenges and required solutions.

30.11 Conclusions

The quest for a sufficient and sustainable energy supply is a global issue of strategic relevance. This has been recognized widely in the many incidents of technical and economic dysfunctionalities of the globalized fossil-based energy industry. It is also emerging that energy supply and climate protection are two aspects of the same challenge.

Most efforts to cope with the challenge are directed towards enabling strategies put forward by the international industry, dovetailed with national short-term interests of various political kinds. Climate protection targets, protectionism to industry sectors and regional interests are among the causes retarding a science-based rational treatment of the situation acceptable for the global community.

Science would have to play a pivotal role in this situation. It is the only institution that can provide a basis of facts free of political or economic interests. It would have to deliver reliable information for decision makers in industry and politics. Moreover, it would have to construct a sustainable basis for creating the technology options required to make responsible strategic decisions. Such decisions are frequently demanded within short timescales. The need to sustain the value of capital investments and the target of minimizing the consequences of climate change are helping to drive this trend. For the most part, science is still not prepared to meet this challenge and does not see that its efficiency needs to be optimized between creativity and responsible priorization.

The analyzing and modeling part of climate science has made an impressive effort to coordinate its actions under the umbrella of the IPCC, which may still need improvement.[33] This truly global science organization may serve as a prototype for other energy sciences that have to provide the solution strategies and serve those who bear the responsibility for implementation. In these areas of science, encompassing both natural and social disciplines, globally responsible and sustainable operation is still lacking, resulting in disorientation, duplication of activities and overall inefficiency. The present chapter does not advocate a gigantic coordinating structure. Instead, it calls for a global network to provide a blueprint for a hierarchical structure of energy science. This hierarchy would be multi-dimensional in traditional disciplines and in the distribution between theoretical and applied research. In such a strategy the hurdles of lacking communication, dissemination and archiving the research efforts should be solved, as all the technology required is at our disposal.

The role of chemistry in its cross-disciplinary role of EnerChem could be pivotal as its globalized culture and proven performance constitute critical factors for success. Moreover, the multiple contributions chemistry can deliver to energy science qualifies this discipline as a key player among the classical disciplines in the areas of energy conservation as well as regenerative energy storage and use. Its output is knowledge critical to the engineering sciences. They will have to

[33] See chapter 31.

provide multiple regionalized solution strategies that fit within the global boundary conditions of sustainability and scalability. Such a functional distribution of tasks cannot be created by fiat, but requires self-organization motivated by mutual exchange and understanding. This casts global dissemination and discourse in a critical role. The development of infrastructure and funding are needed to optimize existing efforts and structures that are based largely on individual and temporary activities. Funding agencies must orchestrate this in a globalized manner without killing the creativity of emerging solutions.

Energy is an area where science, society and economy meet in a critical discourse. The fact that the present energy supply is fully globalized through economic players and international political bodies (IEA, OPEC) requires an equally globalized response from the sciences. This is a dimension of scientific activity comparable to the nuclear challenge, to high-energy physics, astronomy or the exploration of space, all of which serve as positive examples for science operating responsibly in the global dimension. Any truly stable solution to the energy issue can be achieved at a reasonable price and with a minimum of socio-political tensions only if global science lives up to this expectation. The present dominance of the economic factors is a result of the lack of organization of the bodies of knowledge providing sufficient deep and wide insight to those who determine the societal boundary conditions. In this way energy science is a test example of our ability to organize local needs within a set of global boundary conditions.

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Chapter 31
Climate Change as a Global Challenge – and its Implications for Knowledge Generation and Dissemination

Daniel Klingenfeld and Hans Joachim Schellnhuber

Climate change as a global challenge has facilitated the emergence of global structures in knowledge generation and dissemination that stand out in their level of integration. Even against a world that has been subject to the forces of globalization, this process seems unparalleled. In this context, we argue that a democratization of climate change knowledge has taken place, coupled with bottom-up processes in generating new knowledge that can help advance the scientific understanding of and response strategies to this complex issue.

To understand the magnitude of the science effort in this area over the past decades, we set out with a succinct presentation of the natural science basis of climate change and possible impacts of the change processes on ecosystems as well as on human civilization. The scale and scope of the phenomena at play require a global approach to tackling this challenge and demand a sound scientific basis to underpin far-reaching societal choices on how to shape the future. Here, the Intergovernmental Panel on Climate Change (IPCC) continues to play a critical role in providing an objective, fact-driven evaluation of the state of knowledge as an analysis and decision tool for policymakers, but whose reach in knowledge dissemination is much broader.

The geographical integration of research cooperation and the cross-disciplinary nature of research are features that we highlight based on the example of recent publications released ahead of the Copenhagen climate negotiations. From the scientific results presented there, the chapter draws the link to the need for global governance and highlights the emergence of local action. We conclude that the knowledge generation process has succeeded in giving all the information necessary to make informed decisions—will humankind act in time?

31.1 The Global Character and Phenomenology of Climate Change

Climate change has emerged as an issue that touches virtually every aspect of society on a global basis. For science, analyzing the problem from all relevant angles has required an unprecedented integration of efforts, both geographically across the globe and topically across disciplines: studying the natural science basis has allowed to evaluate risks, impacts and vulnerabilities and—most importantly—to connect future climatic conditions to individual behavior and collective choices made today.[1]

31.1.1 The Natural Science Basis

There is overwhelming scientific evidence that an increase in the concentration of carbon dioxide (CO_2) and other greenhouse gases in the atmosphere is associated—according to the laws of physics—with an average global temperature increase. Since the late 1950s, instrumental measurements have demonstrated beyond doubt that the CO_2 concentration in the atmosphere is on a steep rise, and that this development is driven almost exclusively by human activities, especially the combustion of fossil fuels and changes in land use. CO_2 concentrations have actually risen from 280 ppm (parts per million) in pre-industrial times to over 385 ppm today—this constitutes by far the highest concentration since at least two million years ago.

Natural changes can also influence the climate, but they do not diminish the relevance of anthropogenic greenhouse gas emissions with respect to climate change. In fact, over the past fifty years, natural effects alone would have had a slightly cooling effect on the planet. For instance, satellite measurements have confirmed a certain decrease in solar activities during the last decades.

Anthropogenic emissions have already considerably affected the heat balance of the planet. Yet the full effects on global warming have so far been masked by local air pollution that, if abated, would lead to a rapid catch-up effect in warming. So-called radiative forcing, measured in watts per square meter of the Earth's surface (Wm^{-2}), constitutes the determining factor for global average temperature. Human activities have already amplified radiative forcing by 1.6 Wm^{-2}. The contribution of carbon dioxide stands at 1.7 Wm^{-2}; other greenhouse gases add an additional 1.3 Wm^{-2}, whereas cooling effects through air pollution (most notably aerosols) reduce forcing by 1.4 Wm^{-2}. Besides particles with cooling effects, soot emissions also contribute to warming but, on balance, a net negative cooling from particle emissions remains. This factor masks almost half of the overall warming already caused by past emissions. Note that most of the numbers presented in this paragraph come with fairly large margins of error.

With a simple conversion, changes in radiative forcing can be translated into an increase in global average temperature. The best estimate of this so-called climate sensitivity parameter is 0.8°C per Wm^{-2}. This translates into a warming of around 3°C for a doubling of carbon dioxide concentrations over pre-industrial times, which would be equivalent to an increase in radiative forcing of 3.7 Wm^{-2}.

The current human-induced radiative forcing of 1.6 watts per square meter thus corresponds to an already "programmed" warming of 1.3°C—if local air pollution and emissions of aerosols are not further reduced below their current levels!

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[1] For data references on the natural science basis as well as on impacts and vulnerabilities detailed in this section, refer to (WBGU 2009, 9–14).

The thermal inertia of the oceans will delay the establishment of a new equilibrium for several decades, thus explaining the relatively modest global average temperature increase of 0.8°C that has been measured so far. Natural variability in other factors, for example, solar activity, is too small to have a significant impact on these first-order effects.

31.1.2 Impacts and Vulnerabilities: "Avoiding the Unmanageable and Managing the Unavoidable"

The previous discussion has highlighted that even the most ambitious emissions reduction measures on a global scale will not prevent fairly drastic climate change from occurring. What humankind can do, however, is take action to prevent the worst possible consequences and to limit the risks arising from a "business-as-usual" pathway. As one report by the Scientific Expert Group on Climate Change and Sustainable Development to the United Nations put it, the task ahead is "avoiding the unmanageable and managing the unavoidable" (Scientific Expert Group on Climate Change 2007).

Among the risks arising from climate change, the following areas stand out in their potential for large-scale disruptions in nature and society:

1. Sea level rise due to thermal expansion of the oceans and water runoff from melting glaciers and ice sheets. This will take place at an increasing pace as global warming progresses. The average sea level has already risen by 20 centimeters since the 1880s and could rise by over 1 meter by 2100, if greenhouse gas emissions grow unabated. In the long run, the new equilibrium sea level could be many meters higher than today.
2. A higher frequency of extreme weather events, such as heat waves, droughts, strong precipitations, and tropical storms has already been observed. Continued climate change is likely to lead to an increase in their magnitude and occurrence.
3. Global warming of above 2°C will accelerate the loss of genetic diversity, species, and ecosystems, since in many regions temperatures that have not been witnessed for millions of years will be reached over a very short period of time. This would exceed the capacity for adaptation and regeneration of nature and lead to an irreversible loss of entire ecosystems.
4. Anthropogenic carbon dioxide emissions are already contributing to ocean acidification today. This process affects marine organisms that rely on calcium carbonate for their shells and structures. Coral reefs, and thereby an entire food chain on which millions of humans depend, are among the first and most severely affected.
5. Lastly, yet perhaps most importantly, "tipping elements" (PNAS 2009) in the climate system are large-scale components of the planetary machinery which may be pushed into new states or operational modes if critical thresholds of crucial ambient parameters (temperature, precipitation, salinity, etc.)

are crossed. These phase transitions would be in part abrupt, in part irreversible and sometimes both. The consequences in all their magnitude and ramifications are difficult to predict, but are likely to exceed human capacity for a managed and orderly adaptation. Key risks that have been identified are, for example, the potential transformation of the Amazon rainforest into a seasonal forest or a steppe, disruptive changes in ocean currents, erratic behavior of Indian and African monsoon systems, and the destabilization of large ice sheets.

The risks from unmitigated climate change for human civilization, which developed under the remarkably stable environmental conditions of the Holocene, are vast. They include threats to freshwater supplies from melting glaciers, weather extremes, and shifting precipitation patterns. World food production is likely to decrease if temperatures rise beyond 2°C, thus provoking regional food crises. Health risks tend to increase due to the spreading of disease vectors and the amplification of heat waves and extreme weather events. Droughts and soil degradation combined with rising sea levels are contributors to environmental migration, which could reach an unprecedented scale. In addition, the loss of "ecosystem goods and services," which are central to supporting the current economic system, will affect global well-being and particularly nations that depend on agriculture, forestry, and fishing industries. Finally, unmitigated climate change could become a genuine security risk, as it undermines the living conditions and livelihoods of people in many world regions. So the adaptive capacities of many countries could be overstretched, leading to political destabilization, mass migrations and more "failed states" left behind in the process.

31.1.3 The Need for Global, Coordinated Action to Address Climate Change Risks

The dangers depicted above are still avoidable, or at least many of them. The magnitude of the future global temperature increase still depends mainly on *future* anthropogenic greenhouse gas emissions, most importantly carbon dioxide. These are dependent on population increase and economic growth, but can be influenced directly by emissions mitigation measures and climate protection policies. Future emissions can be projected by making assumptions about a range of possible scenarios. If a number of current trends continue without major changes in magnitude and direction, the global average temperature in 2100 could be 3–7°C higher than in the period before the Industrial Revolution. Even in an optimistic scenario—but without strong climate policy—temperatures would rise by 2–3°C. Ambitious climate protection measures are thus required in any case to counter the threats to nature and humankind that science has identified.

Greenhouse gases are global pollutants whose effects on radiative forcing are independent of where they were released. Abatement in one region therefore generates global benefits, but only if this abatement effort is not overridden by rising emissions elsewhere. And the necessary transformation process for every country directly or indirectly touches virtually every aspect of production and consumption, as the current energy system underlying all major economies is based on the combustion of fossil fuels. The modern lifestyle, including the possibility for mobility around the globe, is deeply intertwined with greenhouse gas-emitting processes. Changing the contemporary patterns of unsustainable energy supply will also have far-reaching social implications, since without innovations in the behavioral and institutional spaces no deep industrial transformation can take place.

For the scientific process of knowledge generation and dissemination, the scene is set for a Herculean task with two main dimensions: First, advancing our understanding of the natural processes underlying climate change, from the global scale down to the regional level, in order to deliver assessments of possible impacts and vulnerabilities. Second, mobilizing the vast array of social science disciplines to study potential response strategies to climate change in terms of mitigation and adaptation. Generating actionable recommendations with respect to a global, coordinated effort to address climate change risks is the critical outcome of this integrated effort.

31.2 Responding to a Global Challenge with a Global Scientific Assessment Effort: The IPCC

When attempting to understand the globalization of climate change knowledge and its diffusion beyond the scientific community, one organization stands out as the foremost driver of this process: the Intergovernmental Panel on Climate Change (IPCC). Since its inception over twenty years ago, the IPCC has become the premier scientific review authority on climate change science. Through its work, the organization chiefly contributes to informing decision makers on all levels and to shaping global climate policy.

31.2.1 History and Structure

The IPCC was set up in 1989 by the World Meteorological Institution (WMO) and the United Nations Environment Program (UNEP) to provide the governments of the world and other stakeholders with a balanced and comprehensible scientific view on climate change and its implications for nature and man. Its initial task as defined by UN General Assembly Resolution 43/53 of 6 December 1988 is “to provide internationally co-ordinated scientific assessments of the magnitude, timing and potential environmental and socio-economic impact of climate change and realistic response strategies.” Specifically, the IPCC was tasked to undertake comprehensive reviews and to work out recommendations with respect to:

1. The state of knowledge of the science of climate and climatic change;
2. Programs and studies on the social and economic impacts of climate change, including global warming;

3. Possible response strategies to delay, limit or mitigate the impact of adverse climate change;
4. The identification and possible strengthening of relevant existing international legal instruments having a bearing on climate;
5. Elements for inclusion in a possible future international convention on climate (United Nations 1988).

The IPCC is open to all member countries of the United Nations and the World Meteorological Organization. Its work is overseen by the Panel, which is comprised of government delegations of all member countries, and meets approximately once a year at the plenary level. These sessions are attended by a multidisciplinary group of officials and experts from various national ministries, but also agencies and research institutions. All major decisions, such as, for example, the election of the IPCC Chair and the structure and mandate of the IPCC Working Groups and Task Forces, are made by the Panel. This is meant to ensure the global democratic legitimation of the IPCC. The approval process by the Panel is also designed to shield the analytic efforts from particular national interests and to enhance its political relevance. However, in practice, the close interrelation with the political process is a double-edged sword, because the expectations and demands of decision makers (for instance, in the nomination process for senior IPCC positions) are not always entirely commensurate with the purist scientific attitude maintaining that excellence is the only relevant criterion for picking people and topics. As regards the recent discussion about certain shortcomings in the latest IPCC Assessment Report, the challenge of safeguarding scientific integrity will be discussed later.

From an organizational standpoint, the IPCC is both large and small: while it draws on published science from thousands of researchers around the globe as well as on the voluntary authoring and review efforts of hundreds of high-caliber researchers, as a formal structure the IPCC is relatively small, with a central secretariat planning and overseeing all activities and some professional staff supporting the Working Groups and Task Forces.

The overarching and transdisciplinary nature of the Panel's assessment effort is reflected in the three Working Groups dealing with distinct dimensions of climate change. Working Group I focuses on "The Physical Science Basis of Climate Change," Working Group II on "Climate Change Impacts, Adaptation and Vulnerability," and Working Group III on "Mitigation of Climate Change." The primary products of the groups are the well-known Assessment Reports (ARs) published by the IPCC at regular intervals. The First Assessment Report of 1990 highlighted the importance of climate change as a challenge on a planetary scale and the need for global action to mitigate its long-term consequences. AR1 served as a principal input for the creation of the United Nations Framework Convention on Climate Change (UNFCCC) at the Rio Earth Summit in 1992. To date, the Convention remains the basis for an international approach to tackling climate change, and the role of the IPCC in providing sound scientific underpinnings in this endeavor has been instrumental.

So far, the IPCC has produced four Assessment Reports, which constitute the most comprehensive science review on climate change produced worldwide. The AR2 of 1995 provided decision support in the negotiations leading to the adoption of the Kyoto Protocol in 1997. Reflecting an ongoing process of scientific knowledge production, AR3 and AR4 followed in 2001 and 2007, respectively, and sharpened the world's understanding of climate change risks and its options for action.

In addition to the Assessment Reports, the IPCC has published a range of focused Special Reports on pertinent questions of interest. Further, a Task Force has developed methodologies and guidelines for parties to the UNFCCC in establishing national greenhouse gas inventories. These initiatives complement the Assessment Reports by providing actionable scientific advice on options in policy design.

31.2.2 From Earth System Analysis to Mitigation Economics: Combining Natural and Social Sciences to Derive Policy-Relevant Recommendations

The structure of the Working Groups testifies to the broad mandate for analysis the United Nations conferred to the IPCC in 1988. The task is not only the assessment of the natural science phenomena underlying climate change. The IPCC also has an express mandate to study the role of humans both as driving forces and victims of climate change processes. A third task is to focus on possible mitigation pathways and their environmental, economic, and social implications. The breadth of this mission requires transdisciplinary collaboration to a degree that few, if any, scientific problems have ever called for. In practice, a highly interactive process with a number of discursive feedback loops is necessary to connect the main findings from the three Working Groups and to reflect their interdependencies. Since the "real" future cannot be predicted, as it depends on social choices made today and tomorrow in a self-referential way, scenario analysis covering a wide range of consistent global developments is a useful approach employed by the IPCC. Establishing consensus within and across Working Groups is a challenging process, exemplified in the scenario process: developing integrated scenarios initially involves defining a set of so-called representative concentration pathways (RCP) drawn from peer-reviewed studies and based on a number of socioeconomic assumptions about possible futures. These RCPs serve as inputs into a parallel but interlinked work process among three principal research communities: the climate modeling community (CMC); those concerned with impacts, adaptation and vulnerability (IAV); and integrated assessment modeling (IAM) groups. These research communities from different Working Groups contribute to integrated scenarios that actively take into account a host of feedback loops in the area of human-environment interaction.

The long lag times of the interactive scenario process, along with the requirement to base the modeling effort and the science review only on well-established findings, makes for a certain conservatism in the conclusions of Assessment Reports. As a corollary, it may not be possible to incorporate the most recent scientific results. For example, AR4 included only the sea-level rise due to thermal expansion of the oceans but—explicitly—excluded consideration of melting land ice in its sea level projections. This important additional factor will be incorporated into AR5, thanks to a deeper scientific understanding and quantification of the processes at play.

The role of uncertainty inherent in scientific assessments of most climate change processes leads to probabilistic estimates concerning the biogeophysical phenomena and their resulting impacts on human civilization. Here, the IPCC has linked probabilities to qualitative statements (e.g., "virtually certain" corresponding to a probability level greater than 99%, "very likely" from 90–99%, etc.) to provide better guidance. As progress in science has allowed uncertainties to be lowered over time, one fundamental insight emerges for decision makers: humankind simply holds the future in their hands—for better or worse.

The detailed scientific review and analysis, covering hundreds of pages for every Working Group, is freely accessible, but in its comprehensiveness it is directed above all to an expert audience. A critical communication tool of the IPCC toward the general audience is the Synthesis Report, along with the so-called Summary for Policymakers. These publications focus on the essential findings of the IPCC assessment effort and give an overview on the current state of knowledge across the three Working Groups. Since scientific analysis of a question as complex as climate change often has to operate with probability estimates, these summary documents also indicate the level of confidence that science can attribute to various phenomena. Highlighting the uncertainties, but also the degree of confidence reached in many areas over time, is a critical input into policy-making and of highest relevance for formulating appropriate response strategies.

In analyzing the many dimensions of climate change as well as options for mitigation and adaptation, the IPCC has to be policy-relevant but not policy-prescriptive. This principle is a cornerstone of its work: with its main function being to analyze and to inform, decisions as to actions based on its insights need to be taken elsewhere. As has been mentioned, previous Assessment Reports have prompted landmark agreements, such as the UNFCCC and the Kyoto Protocol. In the current international negotiations for a follow-up agreement to the Kyoto Protocol, the findings of the IPCC continue to play an important role.

Beyond the international and national policy-making arena, the work of the IPCC has had a broad influence on other stakeholders, from worldwide non-governmental organizations dealing with various aspects of climate change, over regional and local initiatives for action on greenhouse gas emissions reductions, to the level of individual citizens. This development is closely linked to the emergence of change agents and, as we will argue, the *democratization of climate change knowledge* that will be discussed later in this chapter.

31.2.3 Learning from Experience: Preparing the IPCC for the Future

The work of the IPCC remains of the highest significance for the process of review, aggregation, and dissemination of climate change knowledge on a global scale. From the viewpoint of history of science, its contribution to broadening the understanding of the complex phenomena associated with anthropogenic global warming cannot be underestimated.

However, thorough external scrutiny of the findings presented in the last Assessment Report has led to the identification of a small number of errors that had escaped the complex peer-review process associated with IPCC work. Without doubt, the shortcomings identified, for example relating to the timescale for Himalayan ice cover loss, require rectification.[2] Yet, when put into the necessary perspective of the several thousands of pages the AR4 is composed of, the public outrage over the mistakes indicates a more severe problem: the public perception of the necessity and credibility of climate change science appears to be highly fragile and susceptible to contrarian campaigns. Obviously, a handful of incorrect details that do not affect any of the main conclusions of the IPCC's work are sufficient to call into question the entire process of this international assessment endeavor along with its scientific bottom lines. This observation shows that, despite all optimism about the globalization of scientific knowledge, a sustainable contract between science and society as reflected by a vital dialogue based on mutual respect and trust is still a distant goal.

It is nevertheless important to point out that on the part of the IPCC the errors made cannot simply be passed over. Three scenarios are possible: the first, and clearly the least desirable, would be to declare its work done and to dismantle the institution. A second option would be to learn from these mistakes, replace some of the responsible authors and make sure to follow the self-imposed strict scientific standards even more thoroughly. In addition, there is a third option worth exploring that would lead to a deeper structural transformation of the IPCC. Such a reform would make the panel even stronger and enhance its scientific results. Currently, due to the role of state actors and political influences, authors are not always selected solely according to their scientific competencies. While its architects mean well in embedding the IPCC to some degree in political processes, hoping to strengthen the link from research findings to decision making, its scientific excellence is partially at risk.

A way out of this dilemma would be to depoliticize the IPCC by putting it under the oversight of the most credible and noble institutions of the scientific community at large, namely the national academies. An important step in this direction was taken in March 2010 when UN Secretary-General Ban Ki-moon

[2] See (IPCC 2010).

together with Panel Chair Pachauri charged the InterAcademy Council (IAC) with an independent review of the processes and procedures of the IPCC. An ad hoc Independent Evaluation Group (IEG) will be formed to conduct this review and to submit recommendations on how to ensure that the highest standards to which the IPCC subscribes will be met today and in the future.

The IAC is well equipped for this task: created in the year 2000 by all science academies around the world, the mission of this institution is to mobilize the leading scholars worldwide with the objective of providing high-quality scientific advice to international bodies around the world. The IAC is led by two co-chairs, both presidents of national academies of science, currently from China and the Netherlands. In preparation of the review process, the IAC will appoint members to the Independent Evaluation Group who will serve as volunteers on a pro bono basis—following close scrutiny of their expertise and after ensuring that no conflicts of interest exist. The review effort will be completed in a timely manner so that the recommendations can guide work on the Fifth Assessment Report, due in 2013.

In this context, we urge that scientific excellence must be the one and only benchmark for the selection of the senior officers and authors of the IPCC and of the quality of the assessed body of information. The IAC could play the role of honest guardian in this context. Finally, another consequence of the errors discovered with immediate practical implications for the work of the IPCC would be to limit the assessment to investigations and data published in first-tier peer-reviewed journals. While such a reform would render the report more fragmentary and imply that a number of important issues are left unaddressed, the scientific standards could be raised further.

31.3 Recent Findings in Climate Change Science Through World-Class Cooperation

The international science review process by the IPCC draws on research activities on a truly global scale. Whereas the policy responses to the climate change problem remain largely in the domain of national initiatives with as yet rather limited global integration and cooperation, climate change science has been fully globalized. This applies both to the natural sciences and the social sciences. The former deal principally with Earth system analysis and climate change impact research; the latter evaluates, for example, climate change policies and their economic implications, but also social and political transformation processes in response to climate change.

The scientific landscape concerning the climate problem—and indeed the structure of eminent science in other disciplines—is much more globalized than many of the other components of society that also have been subjected to the forces of globalization. The political system was already mentioned, but not even the economic system, with its ever-deeper transnational integration can compare to the almost universalistic character of worldwide scientific production. Beyond the requirement for appropriately quoting previously published work, science follows an "open source" process in which arguments of other researchers are critically reflected and developed further. Whereas in the economic sphere intellectual property rights prevent the public use of many ideas and processes, having free access to previous scientific work is the very precondition for advancing our understanding in the breadth and depth that has been achieved over time.

Climate change science is driven by a global community of researchers, in which national boundaries become less and less meaningful. Crucial factors enabling this development are, among others, English as the working language of international scientific exchange, a set of principles for assessing and citing previous work, as well as anonymous peer review to guarantee the quality of the publication and dissemination of knowledge in academic journals. The Internet revolution has made it possible to access this knowledge almost anywhere on the planet and to speed up the process of current and future knowledge generation.

Further reasons for the globalization process in the climate change sciences are to be found in the nature of the problem as well as in the response strategies required. Concerning the nature of climate change, the Earth *system* consists of a large number of coupled processes whose study necessitates global data acquisition and integration. This is especially relevant in understanding the climate system and in developing climate models with explanatory as well as predictive capabilities. Moreover, regional impact studies with a higher resolution that allow possible vulnerabilities to be discerned and contribute to developing appropriate adaptation responses need to be embedded in a systemic view. The fact that every region on the globe will be affected in specific ways, under various emissions and climate scenarios, also explains the interest in local research efforts that help create a dense web in global knowledge production.

When it comes to response strategies to climate change, successful mitigation measures require an aggregate effort by all major emitters in order to have a meaningful impact on global emissions, and on limiting the damages resulting from unmitigated climate change. The task at hand is the successive decarbonization of energy systems on a national, regional, and—in aggregate—global scale.[3] The heterogeneous structure of energy systems around the globe, as well as the far-reaching economic and social implications of these processes of change in different countries, constitute factors that privilege decentralized research efforts. In turn, the results complement and serve in part as inputs into larger-scale global assessments that are heavily model-driven. Not unlike climate models, the complexity achieved with current energy-economy models encourages international cooperation in comparing and evaluating models.

Amidst these ongoing processes, synthesizing knowledge and disseminating it outside the scientific community are two critical tasks related to the climate change problem. They are so important because an adequate response to the challenge involves a far-reaching transformation of our societies that can be driven only by

[3]See chapter 30.

a deeper understanding of the human role in climate change and the risks and opportunities involved. As detailed in the previous section, the IPCC remains the major international institution for this endeavor, being directed at policymakers but also, and equally importantly, at a variety of stakeholders and citizens in general. The complexity of the science review process results in long publication cycles between assessment reports, typically of five to six years. Yet scientific understanding evolves constantly, as does the latitude for making policy.

Two recent scientific publications highlight the latest findings in climate science, and simultaneously testify to the global nature of climate change research. Published ahead of the Copenhagen climate conference in December 2009, they also fulfill a knowledge dissemination function, with the next IPCC Assessment Report not due before 2013. These two documents are The Copenhagen Diagnosis (2009) and A Copenhagen Prognosis (2009)—both titles being emblematic for the reports' envisaged policy relevance.

31.3.1 The Copenhagen Diagnosis

This synthesis report was co-authored by twenty-six leading experts in various fields of climate change science, most of them previous or current IPCC Lead Authors. The focus is on the physical science basis of climate change, corresponding to the range of topics evaluated by Working Group I of the IPCC. Consequently, the areas of expertise of the authors range from ocean physics and ice sheet dynamics to complex systems analysis, including the study of large-scale tipping elements in the climate system.

Beyond the breadth of disciplines of the scholars involved, the Copenhagen Diagnosis testifies to the global nature of research cooperation in the field of climate science: published by the Climate Change Research Center of the University of New South Wales, Australia, the report was co-authored by scientists based in the United States, the United Kingdom, Germany, Austria, France, Switzerland, and Canada.

What is more, the nearly 300 references to recent research articles from scientists working around the globe mirror the decentralized, global knowledge generation process in this domain. Yet, although the research community may be widely dispersed geographically, the publication of the Copenhagen Diagnosis report highlights that knowledge dissemination can nevertheless happen in a coordinated and structured way. In addition, the insights generated are often targeted at a global audience of stakeholders dealing with climate change, in particular policymakers. This is especially true for this science review effort, which was released to inform decision makers at the Copenhagen climate summit about the latest findings in natural science.

In more than one aspect, the conclusions of the Copenhagen Diagnosis indicate that humankind has to act swiftly and forcefully in order to avoid a severe perturbation of the Earth's climate system, likely with unmanageable consequences. Drawing on the latest scientific findings, the report goes significantly beyond the

2007 IPCC Fourth Assessment Report in a number of key areas. Taken together, there is greater scientifically justified urgency than ever to take action on a global scale—if the goal is to confine anthropogenic global warming to a manageable level. Among the key findings, the report cites the following areas of concern, while quantifying the magnitude of the challenge (The Copenhagen Diagnosis 2009, 7).

1. *Surging greenhouse gas emissions*: Despite all previous efforts in climate protection policy, global carbon dioxide emissions from fossil fuels in 2008 are 40% above 1990 levels.
2. *Recent global temperatures demonstrate human-induced warming*: The temperature rise over the past twenty-five years has been 0.19°C per decade, which is in line with model results based on the measured increases in atmospheric greenhouse gas levels.
3. *Acceleration of melting of ice sheets, glaciers and ice caps*: A wide array of different observation and recording techniques demonstrates that the Greenland and Antarctic ice sheets are losing mass at an increasing rate. Melting of glaciers and ice caps around the world has also accelerated.
4. *Rapid Arctic sea ice decline*: Summertime melting of Arctic sea ice has increased far beyond the expectations of climate models. The area of summertime sea ice cover during 2007–2009 was about 40% less than the average predicted by the climate models of the fourth IPCC Assessment Report. This means that the current cryosphere models are too conservative with respect to the responsiveness of the systems in question and need to be improved.
5. *Current sea level rise underestimated*: Satellite measurements peg recent global average sea level rise at 3.4 mm per year over the past fifteen years, around 80% above previous IPCC predictions (which do not account for the full dynamics of the big shelf and inland ice bodies).
6. *Sea level predictions revised*: By 2100, the global sea level is likely to rise at least twice as much as projected by Working Group I of the IPCC AR4. In the case of unmitigated emissions growth, it may well exceed one meter. Even after global temperatures have been stabilized, sea level will continue to surge and several meters of sea level rise can be expected over the next few centuries.
7. *Delay in action risks irreversible damage*: The risk of transgressing critical thresholds, so-called tipping points, grows strongly with unmitigated climate change. Delaying action while waiting for higher levels of scientific certainty could trigger irreversible processes before they are recognized.
8. *The turning point in global emissions must come soon*: If the global average temperature increase is to be limited to 2°C above pre-industrial levels, the peak of global emissions needs to occur between 2015 and 2020, with a rapid and sustained decline of emissions thereafter. To stabilize climate, a decarbonized global society needs to be achieved well within this century.

The main findings of the Copenhagen Diagnosis paint a picture of rapid, human-induced global climate change already happening today and with far-reaching consequences in the future. What is more, the report does not stop at presenting isolated research results, but puts them into the context of an ensemble of global trends with respect to greenhouse gas emissions. It thereby draws the link to societal choices that need to be made today and that will determine the world we will live in tomorrow. The Copenhagen Diagnosis indicates the degree to which global climate science can be a critical input into societal change processes. These can be anywhere in the domain of policy-making, from the international level (for example within the UNFCCC regime) to national or local initiatives. The knowledge generated can also inform lifestyle choices on the level of individual citizens and thus be an input into cultural change over time.

What is important—and mirrors the principles of the IPCC—is the fact that the results presented and the implications drawn are perceived as policy-relevant but not policy-prescriptive. Science can only work with a set of assumptions about *possible* future developments and evaluate the likely consequences of a set of future pathways. In this sense, the principal function, beyond the process of generating knowledge within the scientific community, remains one of informing all other stakeholders. Ultimately, deciding which path the world will take is up to a multitude of actors from various levels, as indicated above. These are the addressees of the Copenhagen Diagnosis.

31.3.2 The Copenhagen Prognosis

Ahead of the Copenhagen negotiations, the Copenhagen Prognosis report (2009) was released as a further science review effort, spearheaded by TERI (The Energy and Resources Institute, India), SEI (the Stockholm Environment Institute), and PIK (the Potsdam Institute for Climate Impact Research). This joint effort by one Asian and two European research institutes takes the most recent findings summarized in the Copenhagen Diagnosis report as a well-defined starting point. The focus, however, is now on possible mitigation strategies as well as on conceivable schemes for sharing the costs of transforming the world's energy system in an equitable way.

The report underscores once again that climate change is a fundamentally global challenge that is intimately linked to development aspects: global carbon dioxide and other greenhouse gas emissions have to peak during this decade and decline rapidly thereafter in order to maintain a realistic chance of confining global warming below 2°C. Concurrently, the majority of a growing world population still has inadequate access to basic energy services. The challenge therefore is not only a decarbonization of the contemporary energy system within its present dimensions, but also the large-scale expansion of energy services on a global level without further aggravating the climate change problem.[4]

[4] See chapter 30.

Science has recognized this conundrum and modeling studies are being undertaken to assess global transformation pathways that take the relevant dynamics into account. The focus is on top-down energy-economy models that rely on a host of technology-specific assumptions along with optimization algorithms. The Copenhagen Prognosis highlights key results of these complex modeling efforts undertaken by a number of international teams. These macro-studies are complemented by more regional, bottom-up analyses that can better take geographically explicit factors into account. Through these complementary approaches, science can help evaluate and manage change processes from a global to a regional level. By assessing possible development scenarios, policymakers receive critical inputs as to the feasibility of alternative emissions pathways, thus enabling them to make informed decisions.

Drawing on the conclusions of the modeling work, the report underscores that, despite the magnitude of the challenge, a global transformation that respects the 2°C guardrail is possible and the economic costs are affordable indeed. This, however, is conditional on timely global action to reverse emissions growth trends. If, in contrast, the world were to delay action until the next decade, future required rates for emissions reductions would result in steep cost increases for mitigation measures.

Yet even if the world acts in good time, the global scope of the transformation process and the need for massive capital investments to deploy more expensive low-carbon technologies requires addressing equity issues. Here, the social sciences have important contributions to make. The Copenhagen Prognosis reviews some previous analyses and concludes that a successful integration of developing countries needs to respond to two criteria: first, ensuring that these countries have the resources necessary to enable rapid and comprehensive decarbonization while, second, still allowing for rapidly improving access to energy services in order to improve the living conditions of millions of people. These requirements call for an unprecedented North-South cooperation, backed by substantial transfers of financial resources and technology.

Beyond agreeing on a global carbon budget for decades to come, the potentially more difficult question—at least politically—will be how to apportion the remaining atmospheric space among humans. At the same time, resolving this question would mean addressing financial transfers from the global "North" to the global "South." Determining what constitutes an equitable distribution that is also politically acceptable is at the heart of the problem. The social sciences have put forward a number of distributional principles that translate the natural science findings with respect to the climate system into policies fit for international implementation. One group of proposals focuses on equal per-capita rights to the atmosphere. Examples include the budget approach (WBGU 2009) or the 2°max climate protection strategy (Wicke et al. 2010). The former will be discussed in the next section. Yet even these schemes with highly relevant distributional consequences for the rich and the poor have been criticized for not sufficiently taking equity into consideration.

The Copenhagen Prognosis presents an alternative approach, termed Greenhouse Development Rights,[5] which defines the development of poorer countries as a central objective. It strives to avoid the conflict and false choice between development and climate protection that could occur under different allocation rules in view of the very limited global carbon budget commensurate with climate stability. Climate protection obligations are defined as a function of capacity (income) and responsibility (past and current emissions) for all individuals who are above a certain "development threshold," measured in GDP per capita. Under this scheme, developed countries would see their emissions allocations decline rapidly to zero and even become negative, which in turn would result in substantial financial flows to poorer countries to help finance a low-carbon development pathway.

By highlighting these policy implications, the Copenhagen Prognosis closes the loop ranging from the natural science foundations of climate change, over economic implications of a great transformation process, to questions of global equity and development. In its summary format, the report can only begin to outline what will need to happen on a planetary scale and where science will once again be an invaluable source of orientation. Indeed, while refining the world's knowledge on the natural science phenomena surrounding climate change will remain an important research task, translating insights into actions is what will matter most when going forward. This is where the need for global governance combined with local action comes into play.

31.4 From Insights to Actions: The Need for Global Governance and the Emergence of Local Action

As has been shown exemplarily in the discussion of the IPCC and recent international science-review efforts, global knowledge generation and dissemination in the biogeophysical realm have solidified our understanding of anthropogenic climate change. Concurrently, interdisciplinary science has turned to proposing new forms of international cooperation designed to mitigate global greenhouse gas emissions in order to avert the worst climatic risks. Next to such top-down approaches, the widespread availability of scientific information together with its purposeful dissemination on various societal levels has also supported the emergence of local change agents with important roles in bottom-up processes. Beyond its globalization, what we have witnessed is indeed the *democratization* of climate change knowledge. Both levels of action—top-down and bottom-up—will be examined below.

[5] Initially developed by Baer et al. (2008).

31.4.1 Science-Based Models of International Cooperation: The Budget Approach

Based on the findings in climate science, a number of proposals have presented blueprints for crafting global climate protection architectures. Developing formulas to divide up the limited atmospheric space for future greenhouse gas emissions is a recurrent theme, and a number of proposals have focused on these distributional aspects.[6] Yet only a relatively limited number of authors have advanced proposals for comprehensive architectures with more specific recommendations for implementation. Concerning a system focusing on the United States only, Stavins (2008) is one example. Addressing the problem on a global scale, the WBGU (2009) and Wicke et al. (2010) have developed overarching climate protection architectures. These proposals have in common a top-down orientation, in which allowable global emissions are determined ex ante and a series of mechanisms are proposed to implement this constraint.

The so-called budget approach (WBGU 2009) is a testimony to the interdisciplinary nature of research at the intersection of the natural and social sciences that is at the basis of scientific proposals for international cooperation to address climate change. The authors of the budget approach, who advise the German government on questions of global change, are experts in fields as diverse as economics, political science, physics, law, engineering and complex systems analysis.

The proposal (WBGU 2009) is based on the latest findings in climate science indicating that the global average temperature increase is determined predominantly by cumulative carbon dioxide emissions, given the long residence time of that greenhouse gas in the atmosphere and the offsetting effects of other emissions. Because of the variability in the natural carbon cycle, and since reversibility of purposeful carbon sequestration, for example, through afforestation, cannot be excluded, WBGU recommends focusing on emissions from fossil fuels. Reducing non-fossil emissions, for example, from land use change, is equally important but should be dealt with in a separate agreement.

The budget approach—*nomen est omen*—first calculates a residual global budget for carbon dioxide emissions from fossil fuel combustion that is compatible with limiting the global average temperature increase to 2°C over pre-industrial levels with a reasonable chance. So establishing the global carbon budget also requires the setting of a (political!) level for the likelihood that the temperature threshold will be respected. Even a modest probability level of 67% yields a total remaining budget for fossil fuel emissions of no more than roughly 750 gigatons of CO_2 during the timeframe 2010–2050. Without policy intervention, global emissions are expected to rise considerably, yet even if they were held constant at current levels the world's "67%-budget" would be exhausted in less than twenty-five years. These facts highlight the transformational challenge that requires unprecedented cooperation on a global scale.

[6] See, for example, (Meyer 2000; Höhne et al. 2005; Baer et al. 2008; Frankel 2008).

What is needed is an equitable model for dividing up the remaining atmospheric space among humans as well as an institutional framework for managing the global carbon budget. In summarizing the Copenhagen Prognosis report, we highlighted several distributional principles discussed in the literature. The budget approach is based on an equal per-capita allocation key in order to determine the remaining carbon budgets on a country-by-country basis. This initial distributional principle results in an emissions allowances allocation that would make most developed countries "carbon bankrupt" in a matter of just a few years, even though the budget period runs until 2050. In contrast, countries with currently very low per-capita emissions—first and foremost a number of developing countries and the group of least developed countries—could still increase their emissions over time given their modest utilization of the atmosphere to date. Overall, however, even developing countries with lower emissions will eventually be constrained and could not duplicate the carbon-intensive and unsustainable development path pursued by other parts of the world.

In order to manage the transition process, it is essential for high emitters to purchase additional emissions certificates. In exchange, low emitters stand to benefit financially from sales of certificates, which would allow them to acquire the resources necessary to enter a sustainable development pathway. A new North-South partnership could thus emerge, in which low-emitting, often poorer countries are not the recipients of altruistic development assistance, but become valuable counterparts for high-emitting countries as sellers of scarce emissions rights. By virtue of the global carbon budget, low-carbon development is encouraged in all countries: nations with budget shortfalls will attempt to reduce emissions swiftly in order to limit allowances purchases, whereas countries with budget surpluses have an incentive to limit their emissions growth and to develop in a carbon-efficient way so as to benefit from the sale of unused allowances.

However, such a planetary partnership requires the existence of a global market for emissions allowances with appropriate oversight and a set of enforceable rules in order to ensure its integrity. The role of institutions is central in this context. WBGU proposes the establishment of a so-called World Climate Bank with statutory powers to ensure that the limits of the global carbon budget are observed. Its principal functions would be to serve as a clearinghouse for allowance transactions as well as to supervise the implementation of so-called national decarbonization roadmaps. These roadmaps lay out country-scale strategies for using the carbon budget in a way that ensures a successive transformation of the energy system while respecting overall emissions limits. Since the strategic behavior of individual countries could jeopardize the integrity of the system, the World Climate Bank needs to be equipped with review and modification powers with respect to national roadmaps.

Establishing an international authority with these relatively far-reaching competencies may seem ambitious or aspirational, perhaps even hopeless given the current status of climate negotiations and the role that national sovereignty plays in the climate policies of a number of key countries. Yet strong arguments point to the need for a previously unknown degree of global cooperation for the world to rise to the challenge. The global emissions constraints derived from the natural science foundations of climate change are simply at odds with the emerging "business-as-usual" trends that cannot be accepted for the sake of humankind. It is more than doubtful whether an uncoordinated approach without overarching enforcement mechanisms can succeed in delivering climate stability.

In addition, economists have often highlighted the efficiency benefits of a global carbon market that leads to emissions abatement where it is least costly and that creates a level playing field for companies operating around the globe.[7] Indeed, delivering climate protection at relatively low cost, as suggested by a number of economic models, depends not only on sustained technological innovation, but also on a geographical and intertemporal optimization of emissions abatements.

The science effort to design global architectures to address the climate challenge has been complemented by the emergence of numerous bottom-up initiatives to take action on a local scale. This development is highly relevant, as small-scale "laboratories of change" pioneer a transformation process that eventually will be scaled up. Given the current difficulties in establishing structures of global climate governance, such first steps also bear political relevance. In fact, the positive experience of rather localized transformation processes can help to overcome the diffuse resistance to more comprehensive efforts.

31.4.2 Emergence of Local Change Agents and the Democratization of Climate Change Knowledge

Path dependencies in the present configuration of institutions, technologies, and infrastructures impede far-reaching societal change.[8] Yet without a deep transformation process, humankind will fail to address the climate change challenge in time, so a path shift is needed—the swift transition to a climate-friendly economy and society. This path shift requires complex learning processes that involve technological innovations but also social change. However, the transformation of societies toward climate-compatibility cannot succeed through top-down policies and new institutions alone. As will be detailed in the last section of this chapter, science-driven policy innovations that focus on incentives for a large-scale transformation are at risk of failure if they are countered by influential players whose approval is critical under constitutional law or in realpolitik. These so-called veto players are all the more effective the greater their number and the more heterogeneously and competitively they operate (Tsebelis 2002).

Change agents are pivotal in overcoming this potential for blockade and in breaking up the stagnation that could long persist. These strategic groups are the

[7] See, for example, (Edenhofer et al. 2008).

[8] The main ideas as to the following discussion of change agents are taken from (WBGU 2009, 46–47).

first to engage in social change and to proliferate an awareness of the opportunities involved. Concrete and positive real world examples can have powerful multiplier effects and are able to counter the gloom-and-doom scenarios spread by opponents to the change process ahead. Indeed, periods of "great transformation" historically have been characterized not only by the emergence of novel lead sectors and the diffusion of new technologies, but even more by the formation of aspiring groups of individuals who advanced change in institutions and mentalities (Rogers 2003). Strategic groups and alliances operate as role models and trendsetters across traditional boundaries—cultural and national—to break the ground for widespread innovation impulses that initially appeared isolated and without any prospects of success. In so doing, change agents call into question traditional and sclerotic worldviews and challenge the status quo. They engender motivation in others to join their cause and become allies.

Change agents can be found in virtually every societal group. Beyond the obvious suspects, such as non-governmental organizations and grassroots groups, they are present, for example, in academia, in companies, and also in policy-making and administrative bodies. The list of actors could be extended and differentiated, but what unites them all is the recognition of both the necessity and opportunity in the decarbonization of society, from the macro level down to the level of the individual citizen and consumer. Initially, change agents often work in isolation and on dispersed projects, which makes them unaware of the opportunities to forge political alliances. Yet elites in decision making positions oftentimes also lack the recognition that among these pioneers potential allies can be found in communicating and enforcing supposedly unpopular policies.

Research in the social sciences has described these phenomena succinctly and proposed ways to use the creative power of hitherto scattered groups to bring about change. This work is based on the recognition that the global climate negotiations will fail if people come to misconstrue climate protection as a purely top-down, state-run operation. While an overarching policy framework like the budget approach is critical in breaking path dependency and in reversing global trends, for every citizen it is equally essential to connect behavior to personal responsibility and agency for change. In other words, what is needed is to break down climate protection targets in a manner comprehensible to citizens, along with an interactive feedback on climate policy up to the highest policy-making level.

Science has proposed a multitude of actions to alert citizens to the far-reaching actions that are required to avoid dangerous climate change. Position papers by think tanks and expert parliamentary debates are important but not sufficient elements. Bottom-up processes also need to contain participatory components that include "non-experts" as people who themselves generate knowledge, take action, and propagate relevant messages. In this process, citizens play more than a passive role of merely absorbing scientific knowledge. They can themselves become sources of new insights relevant for science and society alike. An example of such an active knowledge generation effort is the Reef Check program, in which amateur divers record the state of coral reefs around the world in regular intervals. This effort is a vital source of scientific data, but also an endeavor with social multiplier effects, since the volunteers involved in this program are active in very diverse societal roles and functions.

Further important inputs into the scientific process, especially in the social sciences, can be drawn from bottom-up initiatives in the areas of low-carbon lifestyles as well as projects of adapting to emerging climatic changes. Here, practical insights, sometimes following from trial and error processes, can be suitable for scientific formalization with the possibility for knowledge transfer and further applications. Indeed, the *bottom-up knowledge generation* will be an increasingly important element in responding to the climate change challenge and already plays a vital role in complementing more traditional research-driven science efforts.

That the emergence of change agents is neither directed nor controlled is also a reflection of a widespread science diffusion process that could be described as the *democratization of climate change knowledge*. The publicly available scientific information accessible through the Internet—first and foremost the work of the IPCC, but also recent reports like the The Copenhagen Diagnosis (2009) or the WBGU budget approach (WBGU 2009)—offer the latest insights of top-notch climate change research and point to the need for immediate action. This democratization of knowledge, in which the media and its many distribution channels also have an important role to play, has helped to start a bottom-up process that is essential for the transformation ahead. Change agents make creative use of the existing knowledge in the realm of climate change across all scientific disciplines. The natural science basis has served as an impetus for taking action and for challenging entrenched behavior. Findings in other domains, such as economics and the social sciences more broadly, have paved the way for implementing the critical first steps on a very long road.

31.5 The Limits to Science and Reason?

The previous discussion of climate change has highlighted the role of global science in analyzing the problem, in disseminating knowledge and in proposing action plans to respond to the challenge. Without the comprehensive science effort in this area over recent decades, humankind would be rather ill-equipped to deliver an adequate response: the consequences of our choices as a global community in this area materialize only over time and reach far into the future. In addition, the time lags between changes in behavior and tangible results are often very long. Yet humankind needs to act now in order to shape a future that averts potentially catastrophic changes to the Earth's climate system. Waiting until one looks directly into the abyss and deciding to act then is a fool's strategy.

31.5.1 Successive Decarbonization as a Response to the Climate Threat: Focused Impacts and Widely Shared Benefits

Science has not only pointed to the risks while narrowing remaining uncertainties over time. Science has also sketched a manageable transformation pathway toward a low-carbon society that is associated with only slightly lower GDP growth compared to a "business-as-usual" pathway, as robust modeling results indicate. In fact, as a frame of reference, the overall "growth penalty" of well-designed climate protection policies for the next decades is estimated to be smaller than the GDP losses already incurred through the recent financial crisis in a single year. The benefits of climate protection, i.e. avoided damages of all kind, are not even taken into account when looking solely at the cost of mitigation. Indeed, these benefits are vast and grow over time. They are widely shared among people around the globe—and among all future generations. In addition to the benefits that can be given a price tag since they are relevant for economic output, a host of non-market benefits stand to be reaped, like the preservation of ecosystems as a value in itself.

The path ahead is a successive and comprehensive decarbonization of the world's energy system—which surely will have marked impacts on a number of powerful and influential industries that have been at the basis of the current carbon-intensive development model. It may seem a tautology, but we need to repeat that there can be no deep transformation—which the world urgently needs—without affecting the status quo and thereby a number of focused interest groups.

Indeed, the overall costs of the transformation process, which are small on an aggregate level, will not be spread evenly but will affect certain industries and groups of consumers more than others. Studies in the social sciences have shown that compact but strongly impacted interest groups tend to mobilize more effectively than extended groups that stand to benefit from the transformation process. This argument is particularly valid in the context of climate change, since in addition to uneven impacts from the economic transformation process, the timescales for incurring costs and reaping the benefits from climate protection are different, the latter materializing only over decades with increasing magnitude.

So fierce opposition arises to this envisaged transformation process that would benefit the vast majority of humans on this planet, especially people in poorer countries and those without a strong voice in the current global system. There is a lot at stake for resource holders of fossil fuels whose assets could be devalued substantially if the world were to accept the physical necessities and agree on a global carbon budget. As a consequence, many of these resources would need to remain in the ground and never reach the atmosphere as a combustion product.

31.5.2 An "Industry of Fear": Threats and Misinformation Meant to Derail an Adequate Political Response to Scientific Findings

A great deal of money is being spent on influencing policy-making in a way that, if it does not stop the process of change, at least slows it down and deprives it of some of the momentum that would be crucial in rising to the challenge in time. The likely outcome is what some call "rational" policies that don't rock the boat too much. If the overall level of ambition is not upped significantly, it remains to be seen how rational these policies will be judged only a few decades from now as the world's climate system moves closer to crossing its stable operating boundaries.

The opposition to taking action is grounded in economic interests on the level of companies, but also countries. Oil-rich nations, for example, which generate important rents through resource exports, would be impacted through global climate policies. It therefore comes as little surprise that the chief negotiator for Saudi Arabia at the Copenhagen climate summit is also senior economic advisor to that nation's Minister for Petroleum and Natural Resources. The negotiation strategy of this country strives to discredit scientific information and to call into question the natural science basis of understanding climate change as well as the degree of human influence on atmospheric dynamics. Yet the unanimity principle of the UNFCCC process requires the support of Saudi Arabia and other resource exporters for a global climate agreement. It is hard to see what an adequate regime architecture would have to look like to satisfy the conflicting interests of everyone impacted by the ensuing change process.

A less open but potentially even further-reaching lobbying effort has been carried out by a number of large corporations focusing on national policy-making efforts. The strategies have included, for example, financial support to "alternative scientific voices" attempting to lend credibility to dubious theories that have in common the downplaying of the human role in climate change and therefore the effort to deny the need for action. Direct financial contributions to politicians and parties advocating slower action or denying anthropogenic climate change altogether have also been administered.

In the case of the United States of America, the duet of special interests and key policymakers during the Bush-Cheney years has been aptly described and analyzed by Vanderheiden (2008). Now the arguments have turned toward generating fear of job losses and disadvantages in terms of economic competitiveness if strong climate policies were to be enacted. The recent economic crisis has refocused the attention of many people on the short term and the urgency of acting on climate change may have diminished against other priorities.

Yet against the fear-mongering and deliberate manipulation of the concerns and emotions of people, science has responded with analyses as to how the current crisis can be used productively to respond both to the needs for climate protection and economic recovery. It has been shown that the "either-or" picture that special interests advocate is not grounded in sound reasoning. Proposals for a "Green New Deal" (Edenhofer and Stern 2009) indicate that the crisis is a unique opportunity to direct stimulus spending into low-carbon infrastructure and technologies and to support job creation in industries of the future.

31.5.3 The Jury is Still Out: Will Humankind Act in Time?

In view of the scientific efforts that have been so successful in advancing the knowledge about the world we live in, the outcome of the climate-policy process may look sobering up to now—at least in terms of aggregate results on a global scale. The notable influence of focused interest groups begs the question as to whether science will be confined to a largely descriptive function of global trends and their consequences and to what degree well-founded recommendations will actually lead to appropriate actions.

At the same time, it should be highlighted that science is only one input into the political process and wider processes of social change. Science can inform decision makers and the interested public, but decisions as to actual modifications of a "business-as-usual" development path are made elsewhere. The success of the truly global process of knowledge generation and dissemination with respect to climate change does not guarantee that humankind will draw reasonable conclusions and implement adequate actions in time. Indeed, the fundamental question is whether humans as a species are capable of acting rationally and cooperatively in a long-term perspective—or whether short-term individualistic considerations multiplied a million times render cooperation impossible and make us collectively worse off.

Game theory has explored these questions and attempted to explain human behavior as well as to give clues on how to overcome blockade situations. The prisoners' dilemma is a classic case where mutual cooperation would be beneficial but unilateral defection—or free riding—is a dominant strategy (Nash equilibrium), with everyone losing out as a result. Building trust among parties and establishing enforcement devices, such as international institutions with statutory powers, are ways of breaking out of this dilemma and realizing the best possible outcome. Design proposals for global climate architectures, such as the one by WBGU (2009) take these requirements into account and delineate a way forward, in which nation states surrender some of their national sovereignty to create new global institutions in exchange for an enforceable, time-consistent, worldwide climate protection scheme.

Concurrently, the solution of the climate change problem through successive decarbonization provokes and invokes deliberate veto players who follow very narrow interests and obstruct change for the sake of the vast majority of people on this planet, let alone future generations. These forces are real and powerful; they constitute a serious threat to responding to the climate challenge. The jury is still out as to who will ultimately have more leverage and whether the vast majority of humankind will stand together and act as one.

The globalization process of climate change science and international research cooperation gives grounds for the hope that taking coordinated action on a planetary scale will ultimately be possible. Perhaps the globalization processes observed in science are indeed a precursor to a renewed understanding of humans as a community with much more that unites than divides us. With a sense of shared purpose and destiny, solving the climate challenge is well within our reach.

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Chapter 32
Toward an Epistemic Web

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32.1 Introduction

In the beginning knowledge was local. With the development of more complex forms of economic organization knowledge began to travel. The Library of Alexandria was the fulfillment—however partial and transitory—of a vision to bring together all the knowledge of the world. But to obtain the knowledge one had to go to Alexandria. Today the World Wide Web promises to make universally accessible the knowledge of a world grown larger. To be sure, much work remains to be done: many documents need to be made available (i.e., digitized if they are not already, and freed from restrictive access controls); and various biases (economic, legal, linguistic, social, technological) need to be overcome. But what do we do with this knowledge? Is it enough to create a digital library of Alexandria, with (perhaps) improved finding aids? We propose that the crucial question is how to structure knowledge on the Web to facilitate the construction of new knowledge, knowledge that will be critical in addressing the challenges of the emerging global society.

We begin by asking three questions about the Web and its future. In the remainder of the chapter, we explore the possibility of an "Epistemic Web" in the context of a more general discussion of "knowledge representation technologies," technologies used for storing, manipulating and spreading knowledge.

32.2 What is Fundamentally New About the Web as a Knowledge Representation Technology?

The World Wide Web is a recent phenomenon, but it belongs in a long chain of knowledge representation technologies. In fewer than twenty years the Web has developed from a small tool used by a specialized research community to a technology with more than a billion users, and a volume of data added each year that exceeds the content held, for example, in the Library of Congress by a factor of hundreds of millions. Apart from its rapid growth, what makes the Web different from other knowledge representation technologies?

1. The Web offers a high *impact potential* to an unprecedented number of people. Personal weblogs can receive hundreds of thousands of visitors daily.

2. The Web offers high *collaborative scalability.* Thousands of people (or more) can collaborate in the creation of such products as an open-source operating system (GNU/Linux) or an encyclopedia (Wikipedia).
3. The Web promises nearly universal *interconnectivity.* Discrete documents participate in a vast network of relations to other documents.
4. The Web exhibits exceptional *plasticity.* It can readily accommodate new ways of organizing content as well as new types of content. Content can be changed rapidly and frequently.
5. The Web allows *ambient findability.* Amidst the vast stockpiles of information, desired knowledge can be located almost instantaneously from anywhere in the world (Morville 2005, 6).
6. The Web provides extremely *low latency.* News spreads worldwide within minutes after an event; photographs and telemetry within seconds. Data with radically disparate lifetimes converge: today's news story already finds its place in the encyclopedia.

32.3 What Are the Shortcomings of the Present-Day Web?

None of the Web's distinctive potentials have yet been systematically realized. The present Web remains a prototype of what the Web might become, and of what its founders envisioned (Gillies and Cailliau 2000). The democratizing impact potential is hindered by a "digital divide"—inequality in access to digital sources and services—that results not only from economic disparity but also from technocratic culture, linguistic bias (Paolillo 2005) and the absence of key enabling technologies. Collaborative scalability is limited by the lack of tools for shared annotation of heterogeneous data. Universal interconnectivity cannot be achieved without tools for visualizing and manipulating the complex structures of relations between documents. Plasticity is impeded by the lack of standards for linking non-textual media at a fine granularity. Findability fails without some formal means of disambiguating natural language. And despite the potential of low latency, the time-to-publication of scholarship is scarcely lower on the Web than in traditional print culture, since social practices have not evolved at the same rate as technology.

More generally, however, there is a "central" problem, namely, how to represent human knowledge adequately on the Web. Any solutions that fail to address this problem must fail radically. It is not enough to look to semantics, or social networks, or increased interactivity, or more sophisticated computation—although all these things are indeed useful and necessary.

32.4 What Are the Options for Future Developments of the Web?

Proposals for how to transform the present-day Web abound. The explosion of technology opens up a maze of possible directions for creating a new civic and scholarly infrastructure, an *embarras de richesse*. Three paths have most notably captured the attention of technological visionaries:

1. The idea of the *Semantic Web* was first publicly aired by Berners-Lee and colleagues in 2001; they proposed "an extension of the current [Web], in which information is given well-defined meaning, better enabling computers and people to work in cooperation."[1] In the Semantic Web, documents are enriched with structured metadata to allow for intelligent information retrieval and automated inferences about document content. Ontologies capture the relations between terms within a specific knowledge domain. Semantic Web research has led to the development of potentially fruitful technologies such as RDF (Resource Description Framework) and OWL (Web Ontology Language) (Yu 2007). Yet few compelling applications have emerged so far. Moreover, it is not clear in which context relationships are established or what happens when fundamental disagreement occurs (as it inevitably will). A centralized approach cannot be the solution! To state matters provocatively, the approach to meaning in the Semantic Web resembles the claims of universal validity once offered by the Catholic Church and the Soviet Union. Although the Semantic Web can increase the ability of *computers* to assist in managing the complexity of the Web, it does not solve the problem of how *humans* can integrate the Web into a coherent body of knowledge.
2. *Web 2.0* is a term first used in 2004 not to describe a vision of what the Web *might* become but rather to name a set of *actual* developments that seemed to point to the future (O'Reilly 2005). This is the *Social Web*. Instead of the formal ontologies of the Semantic Web, Web 2.0 evangelists embraced *folksonomies*—a neologism for informal, bottom-up, overlapping classifications created in an egalitarian fashion by users (Morville 2005, 136). Web 2.0 sites allow anyone to add *tags*—short, simple metadata labels—to resources such as photographs and blog entries; other people can then use these tags in searching for resources. Social Web sites such Technorati, Flickr and del.icio.us have become contagiously popular. By allowing for the sharing of sets of tags, these websites connect not just *documents* but also *people*. Web 2.0, in which meaning is assigned not by central authorities but by ordinary citizens, is the Protestant version of the Semantic Web. Yet while this reformation has undoubtedly created a new type of networked community, and although serious scientific applications have emerged (Schröder 2007), it is not clear that such communities can develop into serious scholarly or civic communities organized around a meaningful body of shared knowledge.
3. Futurists envision a *Web of Things* in which *physical objects* become manipulable in many of the same ways that we now manipulate hyperlinked documents. This Web of Things will be enabled by such technologies as low-cost RFID chips, GPS and (in general) the decreasing cost and size of electronic components. Bruce Sterling conceives of Web-enabled things as

[1]See (Berners-Lee et al. 2001; Halpin 2004).

spimes, objects whose changes in space and time are recorded, which can be searched, and around which user communities will form (Morville 2005, 84). Others imagine ubiquitous computing in which computers are embedded in, or can communicate with, everyday objects. These scenarios are derided by critics that imagine a series of (often laughable) interactive appliances—and feared by those that imagine a surveillance society of unprecedented reach. The Web of Things offers the potential of expanding the concept of *document* to include all kinds of physical things that indeed constitute *objects* of human knowledge (Morville 2005, 148). But it too ignores the central problem of how systematically to represent human knowledge itself.

All these paths lead somewhere interesting and we by no means view them as misguided. But we insist that a new way is needed: an Epistemic Web, that is, a universe of knowledge on the Web that parallels human knowledge.

We need a deeper understanding of the relationship between knowledge and representation and how that relation has evolved over human history. Such an understanding will allow us to formulate the challenges for the future and to make a proposal for the development of a new Web that is a plausible continuation of the previous evolution of knowledge representation technologies.

The remainder of this chapter consists of two parts, each of which begins with a theoretical discussion and concludes with a practical analysis. In the first part we articulate the approach to knowledge taken by historical epistemology and provide a brief history of knowledge representation technologies. In the second part we use three fundamental premises about knowledge to explore the challenges for the future development of the Web and conclude with concrete proposals for the Epistemic Web.

32.5 Knowledge: The Perspective of Historical Epistemology

Historical epistemology, as explained in the introduction (chapter 3), is the study of the historical development and transmission of knowledge in light of social, cultural and cognitive factors and with attention to the interaction between individual thinking and institutionalized systems of knowledge. And as is also explained in the introduction, knowledge is not representation-independent, and the media of knowledge representation affect the structure of knowledge. Once knowledge is represented externally, it is subject to transfer in a knowledge economy. Particular knowledge representation technologies shape this economy in different ways, since these technologies vary along a set of economic dimensions:

1. *Portability*: Can a representation travel? How fast? Radio and television broadcasts propagate very quickly, whereas inscribed monoliths generally don't move at all.
2. *Durability*: How lasting is a representation? Cuneiform tablets have endured for thousands of years; spoken language has vanished without a trace.

3. *Ownership*: Who has access to the means of production? How easily can this access be controlled? It is considerably easier to regulate printing presses than pen and ink.
4. *Rivalness*: Does an individual's use of a representation decrease the value of that representation for others? Only one person can read a manuscript at a time, but many people can listen to a story teller or watch a television program.
5. *Reproducibility*: At what cost can a representation be copied? Books were more expensive before the invention of printing with movable type; now they can be photocopied inexpensively, and the cost of a digital copy approaches zero.
6. *Interactivity*: How flexibly can a representation be accessed? A monologue can only be listened to from beginning to end; parts of a book can be skipped or re-read; an electronic text can be searched in more powerful ways.
7. *Recursiveness*: Can higher-order knowledge about a representation be externalized and integrated with the representation? Books can be annotated in the margins, but electronic texts can be annotated more extensively and easily; a spoken monologue, on the other hand, can't be annotated at all.
8. *Connectivity*: To what degree, and how explicitly, is a representation connected to other knowledge? An epic poem may contain allusions to other literature, but these are less direct connections than the footnotes in a scholarly article or (a fortiori) hyperlinks in a Web document.

People strive to maintain an equilibrium between their own cognitive structures and the environment (Piaget 1985). Knowledge from the environment must be assimilated in the context of what an individual already knows, and internal knowledge representations must be accommodated to knowledge acquired from the environment (for instance from external representations). This process is called *equilibration.* The high degree of interaction between internal and external knowledge representations entails that knowledge representation technologies play a key role in equilibration. Equilibration occurs not only with respect to individual knowledge, but also with respect to shared knowledge. Thus equilibration results from an encounter between local and global knowledge (e.g., prior notions of healing and the body are adjusted when global biomedicine is imported into a culture of traditional medicine)[2], or between expert and egalitarian[3] knowledge (e.g., specialist consensus and non-mainstream conceptions are integrated in the collaborative construction of an online encyclopedia article).

Just as certain factors facilitate or hinder cognitive maturation, certain factors facilitate or hinder knowledge growth in a social context. The growth of shared knowledge depends on equilibration and on a knowledge economy in which knowledge circulates widely, is not lost, is not excessively regulated, can be enjoyed by many, is interactive, is open to recursive processes of knowledge formation, and

[2] See chapter 22.
[3] Cf. (Sanger 2007).

is highly connected. Thus the growth of shared knowledge is shaped by available knowledge representation technologies. We arrive at our vision of the Epistemic Web by reasoning deductively from the factors that facilitate knowledge growth and the technological capabilities of networked computer systems. Before we come to our discussion of the Epistemic Web, we will examine the history of knowledge representation technologies, stressing historical dynamics and the impact of particular technologies for the knowledge economy and the structure of knowledge.

32.6 A Short History of Knowledge Representation Technologies

Much animal and human communication is *context-dependent*; elements of the communicative repertoire are exploited only in response to a specific context. The ancestors of Homo sapiens sapiens developed sophisticated language based on the gestural modality; this language contained *context-independent* elements and was characterized by complex syntax (Armstrong et al. 1995). With the evolution of laryngeal descent, humans became capable of articulating the full range of speech sounds used in modern languages, and syntax was co-opted for the organization of spoken language (although its original function remains for sign language users). Spoken language constitutes the baseline for the knowledge representation technologies that we discuss below. It is portable, if not at all durable, it is difficult to control, and it is not very rival. Dialogic speech has rich potential in terms of interactivity, recursiveness, and connectivity, while monologic speech is highly restricted in these respects.

What follows is a summary of the development of important knowledge representation technologies in human history. Such technologies have their ultimate origin in the first use of symbols, which are known from the Upper Paleolithic. These technologies developed not in direct succession but in overlap, and all persist today. We do not see a simple story of more highly developed technologies replacing more primitive ones. Nor do we find useful the often told story of a few technological "revolutions" that punctuate periods of relative stagnation: the invention of writing, printing with movable type, the Web. The history of knowledge representation technologies rather exhibits complex historical interrelationships between technologies, changing social attitudes toward the technologies, and a dynamic tension between conservatism and innovation.

1. *Mnemotechnics* is unique among the technologies described here in that it involves primarily internal representations. Yet these internal representations are structured in the context of a shared symbol-based technology that is learned, and they involve *loci* that are characteristically dependent upon external representations. Mnemotechnics has its origin in traditions of oral-formulaic poetry that are known in many parts of the world. Verse-form functions as a set of constraints that structure content so that it can be recalled for oral performance multiple times with good accuracy (Rubin 1995). These techniques of formal mnemotechnics (traditionally ascribed to

the Greek poet Simonides in the early fifth century BCE) involve establishing a mental chain of *loci*—typically envisaged as wax tablets or papyri—in a fixed order; the *loci* are internalized and serve as the background against which concepts, arguments, physical objects and words are memorized (Lewis 2006, 7–8). Mnemotechnics was practiced especially widely and with unique sophistication among Roman rhetoricians and in medieval monasteries. In the early modern period, mnemotechnics led to the development of such phenomena as commonplace books and tables of knowledge: "forms of technology that exteriorize the means of recollection used in mnemotechnique" (Lewis 2006, 23).

2. *Writing* arose around the end of the fourth millennium BCE (ca. 3300) in southern Babylon (modern Iraq).[4] The earliest written documents are clay tablets impressed with numerical notations and sealings that likely indicated institutional contexts. Although these documents led eventually to the development of cuneiform writing used for the representation of texts in Sumerian, Akkadian and other languages, the earliest writing constituted a symbol system independent of spoken language and used as an instrument of administration for the construction and control of centralized economic systems. On a parallel track, early writing led to calculating techniques and mathematical concepts.[5] Early documents are very closely tied to their particular administrative context and do not represent background knowledge shared by the social actors in this context; in this respect early writing exhibits much of the context-dependence of face-to-face communication. At the same time, writing, in presenting a system of manipulable symbols, allowed for the emergence of new kinds of reflexivity (Damerow 1996, 46–54).
3. *Glottography* is writing that represents spoken language—although written texts differ in a number of structural ways from speech.[6] The potential of writing as a tool for permanently documenting spoken language was discovered only slowly and with increasing usage. When glottographic writing first emerged in the Fara period (ca. 2500 BCE) it served as a mnemonic aid to recording oral genres (proverbs, incantations, hymns and so forth). Glottography led to an increased awareness of language (Krebernik 2007). Subsequently written and spoken language developed as partly independent, partly interpenetrating systems. Glottographic writing eventually spread widely and diverged greatly in form, in response to differences of language typology, social usage and physical media.[7]
4. *Paper* was made from rags as early as the third century BCE in China, but the technique of papermaking using fresh plant materials is supposed to have been the invention of the Chinese court official Cai Lun in 105 CE

[4] See survey chapter 3.
[5] See chapter 6.
[6] See (Hyman 2006); see also survey chapter 3.
[7] See chapter 5.

(Tsien 1987, 2). In the following centuries, paper improved in quality and popularity, becoming the standard writing material by the third or fourth century. Paper technology spread westward, reaching the Arab world by the eighth century and Europe in the tenth; European manufacture began in the twelfth century (Tsien 1987, 293–303). Paper was a necessary enabling technology for printing (and thus a key advance to increasing the portability and reproducibility of knowledge), which began in China around 700, with movable type introduced by the mid-eleventh century.

5. Although *movable type* had been used for four centuries in China, the printing press, a fifteenth-century German invention, came to have a profound and worldwide effect on the dissemination and production of documents (Eisenstein 1980; Giesecke 1991). It is as a result of this technology that mass literacy was achieved in Europe and other parts of the world in the nineteenth and twentieth centuries. Yet the printing press, for all its potential of empowering the masses with literature, was a technology carefully controlled by the Church or by other authorities. Witness the following report of the attitudes of British colonial officials in India:

   > During the administration of Lord Minto this dread of the free diffusion of knowledge became a chronic disease, which was continually afflicting the members of Government with all sorts of hypochondriacal day-fears and night-mares, in which visions of the Printing Press and the Bible were ever making their flesh to creep, and their hair to stand erect with horror. (Kaye 1854, 247–248)

6. With the Industrial Revolution, new technologies extended printing along several vectors. *Hot metal typesetting,* exemplified by the Mergenthaler Linotype (1886) and Lanston Monotype (1889), increased *automation* by replacing the process of manual composition (in which types were picked one by one from a typecase) with the keyboarding of text (Steinberg 1961, 286). The typewriter, first commercially manufactured in the United States in the 1870s, eliminated the centralized ownership of the means of mechanical production of texts and allowed mechanical technology to be used for the creation of even ephemeral documents. *Teletype* machines, which originated around 1907, allowed for the remote transmission and printing of text.
7. Jacquard's *punchcard-controlled* loom (1804) and Hollerith's *tabulating machines*, developed to deal with the massive data that needed to be processed for the 1890 United States Census, first exemplified modern techniques of information processing (Austrian 1982).
8. The *mass media* of radio and television in the twentieth century allowed for extremely quick dissemination of knowledge to unprecedented numbers of people, but the ease with which they could be controlled and their low interactivity made them ideal tools of propaganda.

9. *Mimeographic* and *photocopy* technologies, by lowering the barriers of cost, skill, and time associated with the reproduction of printed documents, allowed for the flourishing of popular self-published literatures (*samizdat*).
10. The first *digital computers* greatly augmented human capabilities in managing knowledge in political and economic administration, engineering and the natural sciences. Computers led first to advances in the culture of calculation. Their application to text and language processing followed at first only slowly, but led eventually to a revolution in which the computer came to augment through external technology human mnemonic and linguistic capacities.[8]

One aspect apparent in this history is a frequent conservatism, in which features of previous knowledge representation technologies and economies are uncritically imported into new ones. Gutenberg's 42–line Bible of the mid 1450s employed a font of almost 300 characters, including a large number of ligatures, alternate letter forms, accented letters and abbreviations: elements that had in the past arisen to *speed up* the copying of manuscripts but that now *slowed down* reading (Steinberg 1961, 20, 30). In much the same way, scholarly articles on the Web make use of features taken over from the book—such as numbered footnotes—although the hypertext medium offers much better alternatives. In general, this history has been shaped by technology, rather than by the purposeful project of creating a new architecture for knowledge. Knowledge representation technologies hold implications for the forms of knowledge. In Greco-Roman antiquity, for instance, precise citations in texts were extremely rare, as scrolls of papyrus made the checking of sources laborious and time-consuming. Today standardization of publication formats in academia fosters a culture that takes quantity of publications or impact factor (how often and where one is cited) as measures of achievement, although these at best are weak proxies of intellectual merit, and at worst constitute an economy that rewards a high output of low-quality work. By studying how knowledge representation technologies have historically fostered or impeded the growth of shared knowledge, we are afforded a better perspective for redesigning such technologies in the future.

32.7 Challenges for the Future of the Web

We organize our exploration of the challenges for the future development of the Web around three general theses about knowledge. We use these theses to draw conclusions about the design the Epistemic Web should take and discuss present obstacles to this design.

[8] For a recent historical overview, see (Dyson 2012). For the role and meaning of knowledge representation in Artificial Intelligence, see (Brachman and Levesque 2004).

32.7.1 Knowledge Is Collectively Produced and Changes in Quantity and Structure

Traditional media such as print, TV and radio are shaped by and reinforce a sender-receiver model of knowledge production and consumption. In contrast, the actual production and appropriation of knowledge typically occurs in a co-operative manner without such a clear distinction between sender and receiver. In a scientific context, the results of knowledge production quickly become tools for the production of further knowledge. Media favoring efficient knowledge production must therefore support these interactive and recursive features and rely on open accessibility to knowledge. They must also be characterized by an equally open availability and adaptability of tools serving to process and network this knowledge. A co-development of knowledge and knowledge infrastructure is required that allows knowledge producers to participate in the development and adaptation of tools appropriate to their purposes.

The large-scale production of knowledge over history is not simply the accumulation of the expertise of a few outstanding individuals. Rather knowledge is produced under complex and dynamic social conditions, in which external representations play a crucial role in the transmission, appropriation, reorganization and equilibration of shared knowledge. Ideally, therefore, external representations should be dynamic. But traditionally most existing knowledge has been locked into static representations. Thus the processes of the accumulation of knowledge and its restructuring in the aftermath of major conceptual advances remain largely hidden. The integration of old and new knowledge is hindered by the fact that knowledge is fragmented across various media and protected by access control measures that restrict its availability. The complex and dynamic structures of links between documents on the Web represent the relations between different areas of knowledge and in themselves constitute an important kind of knowledge. Yet the present Web lacks means for annotating these structures and creating new knowledge about them; indeed the structures themselves remain largely invisible to both humans and computer agents. Only by increasing connectivity between knowledge and by making the relations between discrete elements of knowledge explicit can the Web overcome the limitations of traditional static knowledge representation technologies.

32.7.2 Knowledge is Produced Recursively

An external representation is internalized, and higher-order knowledge can be formed about this internal representation; this higher-order knowledge can then be converted into a new external representation. The traditional boundary between the production and dissemination of knowledge results from the limitations of prior technologies and now hinders the recursive production of knowledge. New tools are needed to integrate access to existing knowledge with facilities for the production of new knowledge both within and outside science. Existing popular and scholarly publications tend to be superficial, and indeed the traditional media of publication are structured (by limitations of length and established generic conventions) in such a way that such superficiality is almost guaranteed. Publications in computer science don't include executable code. Historians and political commentators rarely reproduce their primary sources, which remain in public—or, worse, private!—archives and collections. Articles in scientific journals don't provide sufficient details to allow for the reproduction of experiments.

Experimental data and historical sources are often reproduced only in a piecemeal fashion that does not allow for verification of the authors' conclusions without extensive research on one's own part. In social and behavioural sciences publications don't allow the production of statistical results due to the fact most of the analyzed micro data is not available because "data protection laws" apply. Moreover, the traditional media of dissemination are not well integrated. Print media contain both images and text, but techniques for linking these are only rudimentary. In recent years, books are sometimes accompanied by other media such as DVDs that allow for the distribution of audio and video, but here the relation between media is even looser. Media are somewhat more tightly integrated in Web publications, but even there they are not linked at a consistent level of granularity or presented with a seamless interface.

Today's social networking sites (in particular Facebook, but also Google+, Flickr and others) function as data silos into which contributions can be pumped, but only extracted—if at all—with extreme difficulties. Shared collections of sources from various platforms are not very easy to realize so that recursiveness is impeded. Moreover, the providers in their "terms-of-use" for these applications authorize themselves to reuse contributions as they see fit. Neither is the problem of sustainability solved. Should Facebook decide to delete contributions, then these simply disappear.

This makes it all the more necessary for knowledge producers to retain possession of their data and to ensure open access to them. Tools such as editorial servers or even the desktop should make it possible for the user to choose through which frameworks their contributions should be made accessible. Contributions should be kept in an accessible standard format, such as XML or Markdown, on an editorial server, remain the property of the owner and be moved whenever necessary to another platform or into another collection at any time. Strategies must be developed to ensure the archiving and long-term availability of contributions on diverse editorial servers. Nevertheless, science platforms have much to learn from Facebook and Co. The possibility of forming groups, having real-time discussions, but also of asynchronous communication can be powerful tools for the production of knowledge.

The quest for open access is not a matter of content communism. Without open access, the Web is bound to replicate the insular structure of information in the print world. Lack of open access constitutes one of the main obstacles to the full exploitation of the potential of the Web to support the recursive character of research and scholarship. But while the actual content in form of digital objects is moving more and more into the public domain, fired by the open-access movement, semantics is becoming increasingly privatized. Google, Facebook and others are monopolizing the relations between documents and the users interacting with them. Google Books, for instance, makes documents openly available as far as possible, but not background structures such as search algorithms and full texts. The requirements of open access hence need to be coupled with those of open source.

32.7.3 Knowledge Includes both Data and Models

The evolution of large bodies of shared knowledge is organized around conceptual models that frame data, but the accumulation of data results necessarily in the periodic revision and substitution of these conceptual models. The contemporary knowledge explosion—not only in the sciences but also in the ever-increasing complexity of social and political life in a global culture—results in an acceleration in the change of conceptual models. To prevent the potential ruptures caused by these changes, it is necessary to integrate conceptual models and data within single representations. Only such an integration will allow for research and thinking that address overarching theoretical concerns in the context of concrete, empirical data—so that we can escape the Scylla of empty speculation and the Charybdis of aimless accumulation of detail. If conceptual models were universally shared, they could safely be left unstated; but models differ between communities and change over time even within a single community. Traditional modes of exposition, both academic and popular, are highly conservative and often assume a shared understanding that does not correspond to reality. The problem of the contemporary fragmentation of knowledge necessitates a plastic knowledge representation technology that accommodates both data and models.

32.8 The Epistemic Web

In this last part of the paper we begin by articulating the fundamental principles underlying our vision of a Web that can represent human knowledge adequately. We next discuss the architectural cornerstones upon which the Epistemic Web can be built. Finally, we are ready to paint a scenario of how the Epistemic Web should function and to indicate the gains we expect it to yield.

32.8.1 Fundamental Principles

The Web will become a universe of knowledge that parallels human knowledge. After a lifetime of laborious memorization, study and intellectual activity, some individuals manage to obtain a set of rich internal representations of knowledge that provide good overall coverage of a single domain. Experts can summon up numerous items of knowledge quickly. But it takes a lifetime to reach this point, and few manage. Moreover, this store of knowledge perishes with its owner; there is no way of imparting the whole to students or readers. The Web of the future offers hope: powerful search tools will allow immediate access to a wealth of knowledge (primary and secondary sources; echoes and commentary; critiques and response) in a random-access fashion that parallels, but supersedes the limitations of, human memory. And the Web will be able to represent not only the complete store of structured knowledge accumulated in a single lifetime by a single expert, but the collective knowledge of humanity, structured with equal care and richness.

Private reading (and browsing) will be replaced by the public creation of information. The present economy of knowledge on the Web is strikingly atavistic, incorporating anachronistic features of print culture that stretch back to Gutenberg and indeed to the medieval scriptorium. A traditional publication—and most Web publications are precisely this—is a freeze-frame of active, dynamic research and thought. The process of publication involves technical and social infrastructure that typically lies beyond the range of a single author. And what is published on the Web is *browsed*—a term that signifies a casual association of documents. In the Epistemic Web, *browsing* will be replaced by the purposeful *federation* of documents. Users will (in accord with their interests and needs) choose which documents to view together; which documents they wish to select as entryways into the universe of knowledge; and which documents should serve as *master documents*, controlling the views of secondary documents. These decisions do not remain *private* (like annotations in books kept at home); rather, they may result in the creation of *public*, shareable knowledge. One person's views will be made available to, and serve as potential starting points for the explorations of, others. Of course, the publishing of federations will be voluntary. On the current Web, user behavior is subject to surreptitious methods of information capture (by advertisers and so forth); the Epistemic Web, by making federation an explicit activity, will give users control over the information they produce.

All data will be metadata, and all documents will be perspectives into the universe of knowledge. Librarians ordinarily conceive of metadata as a canonical structured vocabulary that describes the contents and form of certain knowledge representations. By allowing for greatly enriched links between documents (incoming as well as outbound links; multi-directional links; transitive and intransitive links; links with attached semantic labels; links with specified behaviors), the Epistemic Web will allow documents to describe one another. Since any document can refer to any other set of documents, a document may be understood as a *projection* of the universe of knowledge that is instantiated in the Web. Each document serves as a *perspective* into the entire universe of available knowledge, and the extent of the view from this perspective is a function of the document's degree of connectivity. Thus documents resemble Leibniz's monads, which "are nothing but aspects [*perspectives*] of a single universe" (Leibniz 1898, §57). Any document that is connected to other documents is in one or another sense *about* those other documents, and it can be construed as metadata.

32.8.2 Architectural Cornerstones

To increase interactivity and reflexivity a new paradigm is needed to replace the browser/server paradigm. The knowledge consumer and knowledge producer will merge in the knowledge *prosumer*, a term that describes an individual who "co-innovates and coproduces the products they consume" (Tapscott and Williams 2006, 126). We use the term *interagent* to refer to the key piece of software that will enable the Epistemic Web. The interagent will allow the Epistemic Web prosumer to annotate existing documents and create new documents as easily as the current Web user can browse documents. The interagent, like the Roman god Janus, looks in more than one direction: it is the software that mediates interactivity; it allows information production as well as consumption; and it breaks down the division between browser and server. We envision the interagent as a thin client that runs on a user's computer, but that is radically extensible through Web services. Not only does the interagent provide access to the universe of knowledge; it brings a *world of services* to the prosumer's desktop. The interagent can extend its repertoire of behaviors by discovering and utilizing services available on the Web—for instance, when it encounters a new document type, or a new natural language, or a new set of technologies for working with data of a particular type.

A key way of extending knowledge on the Epistemic Web is federation of documents. A group of *federated documents* is brought together by means of a *federating document*. For example, a collection of geographical data sets may be federated into a *mappa mundi*. Or several editions, translations, and commentaries on a literary work may be federated into a *synoptic edition*. In general, federation is a way of bringing together knowledge from existing documents to represent new knowledge. Whereas in the traditional Web the structures of links between documents are mostly hidden and do not allow for annotation, in the Epistemic Web these structures will be exposed as federating documents containing enriched links. In turn such federating documents may be annotated or recursively federated. The interagent will offer facilities for federation, which will be assisted by content analysis technologies that can automatically create provisional federating documents; these documents will then be available for extension and modifications by humans.

32.8.3 Scenario

The Epistemic Web will not be built all at once. Innovation demands the narrowing of the gap between developers and users. The architects of the next-generation Web can promote a technically informed public by creating powerful, flexible and modular tools that are easy to learn, easy to use, and guaranteed not simply to disappear one day. The creation of such tools is an ideal task for the flourishing open-source software community. New technologies will arise from a *virtuous circle* in which technical developments support knowledge production, which in turn leads to new technical developments. Compelling applications will attract users, leading to positive network externalities, more contributors and further gains.

The Epistemic Web depends, of course, on content. Digitization of current knowledge stores is essential but is not enough: knowledge must be accessible, findable, and available for the recursive production of new knowledge. Here there are technical challenges as well as the legal and social challenges of evolving property rights and data protection measures to fit the new knowledge economy. Open-access content is crucial for the growth of knowledge.

The development of knowledge in new areas will necessitate new epistemic models for federating documents. Current models such as the encyclopedia model (exemplified by Wikipedia) and the geospatial model (exemplified by Google Earth) are powerful structures for organizing a large amount of knowledge. But they ultimately are only incremental improvements on content models that have been in use for more than a millennium. As we begin systematically to explore new large-scale topics, such as the comparative study of globalization processes in history and social sciences, we will need new knowledge representation forms to accommodate such phenomena as layered time developments within a geospatial context. One research area of considerable importance is visualization methods, that is "systematic graphic formats, that can be used to create, share, or codify knowledge" (Lengler and Eppler 2007).

The Epistemic Web will have to be a sustainable ecology of knowledge, affording a place for established knowledge and creating space for new knowledge. There will be niches for grassroots innovation as well as for conservative institutions. The Web will grow in an *innovation-stabilization* cycle. Some innovations will showcase powerful new ideas that need to be reimplemented with greater generality. Some innovations will serve the purpose for which they were constructed, and all that will be needed is an infrastructure to ensure their longevity. Some innovations will be dead ends; they can be forgotten, or remembered only as negative examples. Stabilization will ensure that the Web is not cobbled together from prototypes and experiments. Successful innovations will become infrastructure that allows for the next wave of innovation.

The accumulation of knowledge is only possible when mechanisms exist to ensure reliability. Knowledge must be grounded at a low level. In established genres of writing, baseless statements can be couched in the language of authority, allowing them to masquerade as reliable knowledge. Ultimately, higher-level knowledge must be grounded in low-level, concrete, foundational knowledge. A knowledge representation technology based on the principle of high connectivity will help ensure that there is a chain of explicit links that allows knowledge to be verified.

Current discourse about the Web centers around *information*, a word that suggests an undifferentiated, interchangeable commodity, and which is often used in an imprecise way that reflects a "conceptual creolization" (Nunberg 1996). Knowledge, by contrast, is highly structured and is tied to agents: it is what individuals, or social groups, or all people know. Knowledge arises dynamically through equilibration processes. The Epistemic Web constitutes a novel technology that accommodates both local and global, both egalitarian and expert knowledge. By allowing for the equilibration of such disparate kinds of knowledge on an unparalleled scale, the Epistemic Web will make possible the next stage in the globalization of knowledge.

We have presented a scenario for the Epistemic Web that poses considerable technical and social challenges. We believe, however, that new thinking is needed to transform the Web into a technology that facilitates the production of knowledge in a complex global society. Left to develop in a haphazard fashion, the Web will not spontaneously evolve in an utopian direction. Indeed, the alternative to an Epistemic Web may be a Web in which there is a growing digital divide of competence, a commercial monopoly on content, de-facto monopolies of content due to unsolved data protection problems, a lack of open standards and infrastructure, restrictions on innovation, and ultimately a forking into two Webs: a Web of slick, mainstream content for the many; and an underground, alternative Web for the few.

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Index

Key entries in boldface

D

I

J

K

L

M

Q

R

S

T

Z